United States Environmental Protection Agency	Office of Ground Water and Drinking Water (4601)	EPA 817-D-06-003 June 2006

SIMULTANEOUS COMPLIANCE GUIDANCE MANUAL (DRAFT)

FOR THE FINAL STAGE 2 M-DBP RULES

1

1   This page intentionally left blank.

Note on the Simultaneous Compliance Guidance Manual (DRAFT) for the Final Stage 2 Microbial and Disinfection Byproducts Rules

Purpose:

The purpose of this guidance manual is to provide technical information for water systems and states to assist them with complying with the Stage 2 Disinfectant and Disinfection Byproducts Rule, the Long Term 2 Enhanced Surface Water Treatment Rule, and other Safe Drinking Water Act (SDWA) regulations. This draft version of the guidance manual is specifically intended for stakeholder comments. This guidance is not a substitute for applicable legal requirements, nor is it a regulation itself. Thus, it does not impose legally binding requirements on any party, including EPA, states, or the regulated community. Interested parties are free to raise questions and objections to the guidance and the appropriateness of its use in a particular situation. Although this manual describes many methods for complying with SDWA requirements, the guidance presented here may not be appropriate for all situations, and alternative approaches may provide satisfactory performance. The mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Authorship:

This manual was developed under the direction of EPA's Office of Ground Water and Drinking Water and was prepared by The Cadmus Group, Inc. and HDR, Inc. Questions concerning this document should be addressed to:

Tom Grubbs or Jimmy Chen
Office of Ground Water & Drinking Water
U.S. Environmental Protection Agency
Mail Code 4607M
1200 Pennsylvania Avenue NW
Washington, DC 20460-0001
Email: grubbs.thomas@epa.gov or chen.jimmy@epa.gov

Contents

Appendices

List of Exhibits

Acronyms

4	AOC	Assimilable Organic Carbon
5	As(III)	Arsenite
6	As(V)	Arsenate
7	BAT	Best Available Technology
8	BMPs	Best Management Practices
9	BDOC	Biodegrable Dissolved Organic Carbon
10	CDPHE	Colorado Department of Health and Environment
11	CFE	Combined Filter Effluent
12	CPE	Comprehensive Performance Evaluation
13	CT	Disinfectant Residual Concentration $\times$ Contact Time
14	CWS	Community Water System
15	DBP	Disinfection Byproduct
16	DBPR	Disinfectants and Disinfection Byproducts Rule
17	DE	Diatomaceous Earth
18	DO	Dissolved Oxygen
19	DOC	Dissolved Organic Carbon
20	EBCT	Empty Bed Contact Time
21	EPA	Environmental Protection Agency
22	FBRR	Filter Backwash Recycling Rule
23	IESWTR	Interim Enhanced Surface Water Treatment Rule
24	GAC	Granular Activated Carbon
25	GWUDI	Ground Water Under the Direct Influence
26	HAA	Haloacetic Acid
27	HAA5	The Sum of Five HAA Species
28	HOCl	Hypochlorous Acid
29	HPC	Heterotrophic Plate Count
30	HRT	Hydraulic Residence Time
31	ICR	Information Collection Rule
32	IESWTR	Interm Enhanced Surface Water Treatment Rule
33	IFE	Individual Filter Effluent
34	LCR	Lead and Copper Rule
35	LRAA	Locational Running Annual Average
36	LT1ESWTR	Long Term 1 Enhanced Surface Water Treatment Rule
37	LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
38	MCL	Maximum Contaminant Level
39	MCLG	Maximum Containment Level Goal
40	M/DBP	Microbial Disinfection Byproducts
41	MF	Microfiltration
42	MGD	Million Gallons per Day
43	MRDL	Maximum Residual Disinfection Level
44	MRDLG	Maximum Residual Disinfection Level Goal

1	MWCO	Molecular Weight Cutoff
2	NF	Nanofiltration
3	NOM	Natural Organic Matter
4	NTNCWS	Nontransient Noncommunity Water System
5	NTU	Nephelometric Turbidity Units
6	OCl	Hypochlorite Ion
7	PAC	Powdered Activated Carbon
8	POTW	Publicly Owned Treatment Works
9	PWS	Public Water System
10	SDWA	Safe Drinking Water Act
11	SDS	Simulated Distribution System
12	SOC	Synthetic Organic Chemicals
13	Stage 1 D/DBPR	Stage 1 Disinfection and Disinfection Byproducts Rule
14	Stage 2 DBPR	Stage 2 Disinfectants and Disinfection Byproducts Rule
15	SUVA	Specific Ultraviolet Absorbance
16	SWTR	Surface Water Treatment Rule
17	TCR	Total Coliform Rule
18	TDS	Total Dissolved Solids
19	THM	Trihalomethane
20	TTHM	Total Trihalomethane
21	TTHMFP	Total Trihalomethane Formation Potential
22	TOC	Total Organic Carbon
23	UF	Ultrafiltration
24	UPS	Universal Power Supply
25	UV	Ultraviolet Light
26	VOC	Volatile Organic Compound
27	WTP	Water Treatment Plant
28	WWTP	Wastewater Treatment Plant
29		

1
2
3
4
5
6

1 Introduction

7
8   The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) and the Stage
9   2 Disinfectants and Disinfection Byproducts Rule (DBPR) were developed and promulgated
10   together to address risk trade-offs between two different types of contaminants: microbial
11   pathogens and disinfection byproducts. EPA recognizes that systems may encounter compliance
12   issues with the Stage 2 DBPR when making changes to comply with the LT2ESWTR, and vice
13   versa. In addition to the challenges of complying with the suite of microbial/disinfection
14   byproduct (M-DBP) rules simultaneously, a water system must also ensure that changes in
15   treatment do not adversely affect compliance with other drinking water regulations.
16
17   This chapter answers the questions:
18
19   1.1   What is the purpose of this guidance manual?
20   1.2   What is "simultaneous compliance"?
21   1.3   Does this manual address compliance with environmental regulations other than
22   Safe Drinking Water Act regulations?
23   1.4   Who should use this guidance manual? How should it be used?
24   1.5   How is this manual organized?
25   1.6   Can I rely on this guidance manual alone to make compliance decisions?
26   1.7   Are there quick references I can use to screen for potential simultaneous
27   compliance problems?
28   1.8   What additional resources are available?
29
30   **1.1   What is the purpose of this guidance manual?**
31
32   The purpose of this guidance manual is to
33   help water systems and their regulators *identify*
34   *and mitigate* potential simultaneous compliance
35   issues that may arise when systems make changes
36   to comply with the LT2ESWTR and/or the Stage 2
37   DBPR. The manual also lists possible ways that
38   simultaneous compliance issues could be
39   addressed. In addition, tools are recommended and
40   described to help determine if potential issues may
41   affect a given system
42

> **This manual addresses simultaneous compliance issues that may arise as systems make treatment changes to comply with the LT2ESWTR and/or the Stage 2 DBPR.**

1   Another key purpose of this manual is to provide a ***clearinghouse of information***,
2   directing the reader to helpful resources. It would not be practical for one document to contain
3   comprehensive technical and operational information for all of the Stage 2 DBPR and
4   LT2ESWTR compliance treatment technologies. Instead, EPA has designed this manual to raise
5   potential simultaneous compliance issues, and directs readers to other references for more in-
6   depth information.
7
8   **1.2   What is "Simultaneous Compliance"?**
9
10   For the purposes of this guidance manual, simultaneous compliance means compliance
11   with ***all existing Safe Drinking Water Act (SDWA) regulations***, as summarized in Exhibit 1.1.
12   Two-page fact sheets for many of the regulations are included in Appendix A. While systems
13   may be concerned with issues pertaining to emerging contaminants, this guidance manual is not
14   designed to address these concerns and does not discuss these issues.
15
16   **1.3   Does this manual address compliance with environmental regulations other than**
17   **   SDWA regulations?**
18
19   In addition to regulatory issues, systems should always weigh operational issues and
20   compliance with other environmental regulations when considering a treatment change. While
21   this document provides some discussion of non-SDWA regulations and other compliance
22   challenges (e.g. discharge permits, sludge disposal), readers should seek additional guidance and
23   other technical references for addressing these compliance issues.
24
25   **1.4   Who should use this guidance manual and how should it be used?**
26
27   This manual should be used by systems
28   that already know they need to make a change to
29   comply with the requirements of the LT2ESTWR
30   and/or the Stage 2 DBPR. It is intended to serve
31   as a tool for systems and their regulators as
32   systems select a treatment alternative or
33   operational change. Example 1.1 shows how
34   managers of a hypothetical system could use this
35   manual as they decide on treatment changes to
36   comply with the LT2ESWTR. Example 1.2 shows how a regulator working with the same
37   hypothetical system could also use this guidance manual as a technical resource.
38

> **This manual is for systems that already know they need to make a change in operations or treatment. It can also help regulators evaluate proposed changes.**

1

Exhibit 1.1 Existing SDWA Regulations as of March, 2006

2

Rule	*Date of Promulgation*	*Contaminant of Concern*	*Rule Summary Information Available from EPA*
Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)	December 2005	Microbial Pathogens	Fact Sheet, included in Appendix A
Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR)	December 2005	Disinfectants and Disinfection Byproducts	Fact Sheet, included in Appendix A
Arsenic and Clarifications to Compliance and New Source Monitoring Rule	January 2001	Arsenic	Quick Reference Guide, included in Appendix A
Lead and Copper Rule (LCR)	June 1991	Lead and Copper	Quick Reference Guide, Included in Appendix A
LCR Clarification of Requirements for Collecting Samples and Calculating Compliance	March 2004	Lead and Copper	Fact Sheet, included in Appendix A
Total Coliform Rule (TCR)	June 1989	Microbial Pathogens	Quick Reference Guide, included in Appendix A
Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 D/DBPR)	December 1998	Disinfectants and Disinfection Byproducts	Quick Reference Guide, included in Appendix A
Interim Enhanced Surface Water Treatment Rule (IESWTR)	December 1998	Microbial Pathogens	Quick Reference Guide, included in Appendix A
Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR)	January 2002	Microbial Pathogens	Quick Reference Guide, included in Appendix A
Filter Backwash Recycling Rule (FBRR)	June 2001	Filter Backwash (Microbial Pathogens)	Quick Reference Guide, included in Appendix A
Surface Water Treatment Rule (SWTR)	June 1989	Microbial Pathogens	Summary information on the web at http://www.epa.gov/safewater/therule.html#Surface

1

Example 1.1 How this Manual can Help Water System Personnel Better Understand Their Choices

System A is a community water system serving filtered surface water to 11,000 people. Based on past source water *Cryptosporidium* monitoring, System A will likely be placed in the second LT2ESWTR bin and therefore will need an additional 1.0 log *Cryptosporidium* removal or inactivation. The system hired an engineer to conduct a feasibility study. The engineer recommended three possible compliance options:

- bank filtration
- bag filters
- ozone

Before recommending any of them to their water board, System A wanted more information on each technique. In addition to worrying about costs and operational challenges, the staff is concerned that making a change to comply with LT2ESWTR might put them out of compliance with another drinking water regulation.

System A picks up this *Simultaneous Compliance Guidance Manual* and

- Refers to Chapter 2 for summaries of the issues that pertain to these three treatment alternatives.
- Reads Section 4.4 *Other Microbial Technologies* in Chapter 4 for information on simultaneous compliance issues associated with bank filtration and bag filters.
- Reads Section 5.2 *Ozonation* in Chapter 5 for information on simultaneous compliance issues associated with ozone.
- Gets additional references about bank filtration, bag filters, and ozone from Chapter 7.
- Reviews Section 5.5 *Primary and Residual Disinfectant Use* in Chapter 5 to see what issues might arise using the combination of ozone as primary disinfectant and free chlorine as residual disinfectant.
- Based on their reading, System A want to know more about whether they might have distribution system biofilm problems from switching to ozone. They refer to Appendix C *Guidelines for Evaluating Potential Impacts of Treatment Changes on Distribution Systems* and read the section on adding ozone and the section on installing ozone without subsequent biological filtration.
- System A decides it would be beneficial to know how each of the treatment alternatives could be evaluated more <u>before</u> installation. They read through Section 6.3 *Tools for Gathering Information* and identify tools that may be helpful for evaluating the three alternatives.

While they still have many questions for their engineer and have not yet chosen a treatment technique, System A's managers feel more prepared to discuss the pros and cons of each alternative. They have identified questions they would like answered before they take the next step.

2

1
2

Example 1.2 How This Manual Can Help Regulators Understand Potential Simultaneous Compliance Issues

The state has just received notification of System A's intent to install ozone treatment to comply with the LT2ESWTR. The state's engineers are concerned that this change could potentially make it difficult for System A to comply with other regulations. They're particularly concerned with bacteriological regrowth in the distribution system.

They pick up this *Simultaneous Compliance Guidance Manual* and

- Read Section 5.2 *Ozonation* in Chapter 5 for information on simultaneous compliance issues associated with ozone.
- Refer to Appendix C *Guidelines for Evaluating Potential Impacts of Treatment Changes on Distribution Systems* and read the section on adding ozone and the section on installing ozone without subsequent biological filtration.
- Read Case Study #10: Ozonation for an example of how one water system used ozone to control microbial regrowth potential in the distribution system.

The regulators have many questions for System A, but are prepared to discuss the proposed treatment technique with them.

3
4
5
6
7

1   **1.5   How is this manual organized?**
2
3   Exhibits 1.2 and 1.3 summarize the contents of each chapter and appendix in this
4   guidance manual.
5
6   Chapter 2 provides tables that summarize the potential benefits and conflicts of
7   LT2ESWTR and Stage 2 DBPR compliance technologies, operational issues that should be
8   considered, and tools that systems can use to consider a treatment technology's potential for
9   causing simultaneous compliance problems.
10
11   Chapters 3 through 5 of the manual are organized by ***treatment technique***. This enables
12   the reader to refer to a particular section for a comprehensive discussion of simultaneous
13   compliance issues related to that treatment technique. For example, if the reader is considering
14   installing chloramines to achieve compliance with the Stage 2 DBPR, the reader should refer to
15   Section 5.1 for a discussion of pertinent simultaneous compliance issues that relate to using
16   chloramines. Within these chapters, each section on a treatment technique is organized as
17   follows:
18
19   • A summary of **Advantages** of the treatment technique
20
21   • **Potential Operational and Simultaneous Compliance Issues**, including
22   recommendations for addressing each issue
23
24   • **Recommendations for Gathering More Information**, including suggestions for
25   additional monitoring, tools that are available for collecting additional system
26   information, and a short description of related case studies.
27
28   Chapter 6 identifies issues that should be considered before a change in treatment or
29   operations is made. It also describes tools available to help systems collect information that is
30   applicable and helpful for making their compliance decisions.
31
32   Chapter 7 provides a complete reference list, grouped by subject and also listed
33   alphabetically. Most of the subject headings in Chapter 7 correspond to specific treatment
34   technologies. Exceptions include technical references for DBP formation, technical references
35   for corrosion, and general water treatment references.
36
37

1   **Exhibit 1.2 Organization of the Simultaneous Compliance Guidance Manual –**
2   **Chapters**

Ch #...	*is titled...*	*and has information on...*
2	Quick Reference Materials for Simultaneous Compliance	• A checklist to help systems quickly identify simultaneous compliance issues • Tables summarizing compliance, operational, and water quality issues for each compliance technology • Tables summarizing tools and pertinent case studies
3	Improving and Optimizing Current Operations	◆ Source Management ◆ Distribution System Best Management Practices ◆ Moving Point of Chlorination ◆ Decreasing pH ◆ Reducing Chlorine Dose Under Warm Water Conditions ◆ Modifying Presedimentation Basin Operations ◆ Enhanced Coagulation ◆ Enhanced Softening
4	Installing New Total Organic Carbon or Microbial Removal Technologies	• Granular Activated Carbon • Microfiltration/Ultrafiltration • Nanofiltration • Other Microbial Removal Technologies
5	Alternative Disinfection Strategies	• Chloramines • Ozone • Ultraviolet Light • Chlorine Dioxide • Primary and Secondary (residual) Disinfectant Use
6	Making M/DBP Compliance Decisions	Tools available for: • Water Quality Monitoring • Hydraulic and Water Quality Modeling for Distribution Systems • Desktop Evaluations • Bench-Scale Testing • Pilot Testing • Full-Scale Applications • Cost Estimation • Community Preferences
7	References	Technical references grouped by subject and also listed alphabetically

3
4
5

1
2   **Exhibit 1.3 Organization of the Simultaneous Compliance Guidance Manual –**
3   **Appendices**
4

Appendix…	*is titled...*	*and has information on...*
A	Summary of Pertinent Drinking Water Regulations	Summaries of major EPA drinking water regulations in the form of 2-page fact sheets.
B	Case Studies	Case studies illustrating simultaneous compliance challenges that water systems have encountered when implementing treatment techniques to help comply with one or more of the M/DBP rules.
C	Guidelines for Evaluating Potential Impacts of Treatment Changes on Distribution Systems	Summary of issues that may arise in the distribution system as a result of changes made during treatment.
D	Tools for Evaluating Impacts of Treatment Changes on Lead and Copper Rule (LCR) Compliance	Tools that can be used to test impacts of a water quality change on corrosion, which can result in violations of the LCR. References for further information are also included.
E	Programs Water Systems Can Use to Achieve Simultaneous Compliance	Existing and developing programs that can help water systems comply with regulations and produce consistently high quality water. Contains descriptions of performance-driven optimization programs and integrated management approaches that consider treatment processes and operating practices throughout the entire water system.

5
6

1
2 ## 1.6   Can I rely on this guidance manual alone to make compliance decisions?
3
4   No, this guidance manual alone is not intended to provide comprehensive technical
5 guidance for systems making treatment modifications. Instead, systems are encouraged to use
6 this manual as a tool to identify potential issues and possible solutions to those issues. Chapter 7
7 provides an extensive reference list, grouped by subject matter, which systems can use to obtain
8 more information as they plan treatment modifications.
9
10   Each state may have its own rules and regulations pertaining to treatment modifications.
11 For example, many states have review and approval procedures that must be followed before
12 making any compliance decisions. Systems should contact their state or EPA office for further
13 information.
14
15 ## 1.7   Are there quick references I can use to screen for potential simultaneous compliance
16   problems?
17
18   Yes, Exhibit 2.1 in Chapter 2 is a one-page checklist that systems can use to quickly
19 identify key potential operational and simultaneous compliance issues. This checklist could be
20 particularly helpful for small systems or systems with limited resources. Chapter 2 also provides
21 the following summary tables to help systems screen for potential issues:
22
23   • Exhibit 2.2 Technology Alternatives and How They Affect Water Quality
24   • Exhibit 2.3 Stage 2 DBPR and LT2ESWTR Compliance Technologies Summary of
25   Benefits and Potential Conflicts
26   • Exhibit 2.4 Potential Operational Issues for Different Treatment Modifications
27   • Exhibit 2.5 Case Studies in this Guidance Manual and Issues They Address
28   • Exhibit 2.6 Tools for Gathering System-Specific Information on Different Treatment
29   Technologies
30
31 ## 1.8   What additional resources are available?
32
33   Chapter 7 contains a comprehensive list of references, grouped by subject. EPA
34 references are discussed below.
35
36 *The 1999 M-DBP Simultaneous Compliance Guidance Manual*
37
38   The *Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance*
39 *Manual* (USEPA 1999f) was published in conjunction with the promulgation of the Stage 1
40 D/DBPR and the Interim Enhanced Surface Water Treatment Rule (IESWTR). The 1999
41 manual is organized by regulation, describing how compliance with Stage 1 D/DBPR or
42 IESWTR might affect compliance with another regulation, focusing on one regulation at a time.
43 Some readers may be more comfortable with that layout. Since several issues discussed in the

1   1999 manual continue to be issues that present challenges for systems trying to comply with the
2   LT2ESWTR and Stage 2 DBPR, EPA recommends that readers also consider referring to the
3   1999 manual for guidance.
4
5   *Additional EPA References*
6
7   In conjunction with promulgation of the IESWTR, Stage 1 D/DBPR, Long Term 1
8   Enhanced Surface Water Treatment Rule (LT1ESWTR), LT2ESWTR, and the Stage 2 DBPR,
9   EPA has published several guidance manuals that may assist PWSs in resolving potential
10   conflicts. Complete references for these guidance manuals are provided in Chapter 7. These
11   references include the following:
12
13   • *Handbook: Optimizing Water Treatment Plant Performance Using the Composite*
14   *Correction Program* (USEPA 1998a)
15
16   • *Disinfection Profiling and Benchmarking Guidance Manual* (USEPA 1999a)
17
18   • *Alternative Disinfectants and Oxidants Guidance Manual* (USEPA 1999b)
19
20   • *Uncovered Finished Water Reservoirs Guidance Manual* (USEPA 1999c)
21
22   • *Guidance Manual for Compliance with the Interim Enhanced Surface Water*
23   *Treatment Rule: Turbidity Provisions* (USEPA 1999d)
24
25   • *Unfiltered Systems Guidance Manual* (USEPA 1999e)
26
27   • *Guidance Manual for Conducting Sanitary Surveys of Public Water Systems; Surface*
28   *Water and Ground Water Under the Direct Influence (GWUDI) of Surface Water*
29   (USEPA 1999g)
30
31   • *Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual*
32   (USEPA 1999h)
33
34   • *Implementation Guidance for the Stage 1 Disinfectants/Disinfection Byproducts Rule*
35   (USEPA 2001a)
36
37   • *Controlling Disinfection By-Products and Microbial Contaminants in Drinking Water*
38   (USEPA 2001c)
39
40   • *Draft LT2ESWTR Toolbox Guidance Manual* (USEPA 2003a)
41
42   • *Draft Ultraviolet Disinfection Guidance Manual* (USEPA 2003b)

1
2   • *Draft Stage 2 DBPR Implementation Guidance* (USEPA 2006b)
3
4   • *Draft Significant Excursion Guidance Manual* (USEPA 2003c)
5
6   • *Draft LT2ESWTR Implementation Guidance* (USEPA 2006c)
7
8   • *Draft Filter Surveillance Manual* (USEPA 2004a)
9
10   • *Draft Coagulation Control Manual* (USEPA 2004b)
11
12   • *Draft Process Monitoring Manual (USEPA 2004c)*
13
14   • *Membrane Filtration Guidance Manual* (USEPA 2005b)
15
16   Information on future guidance manuals to be published in conjunction with the Stage 2
17   DBPR and LT2ESWTR can be found on EPA's website at
18   http://www.epa.gov/safewater/disinfection/lt2/compliance.html and
19   http://www.epa.gov/safewater/disinfection/stage2/compliance.html.

1   This page intentionally left blank.

> # 2 Quick Reference Materials for Simultaneous Compliance

This Chapter provides matrices that can be used as screening tools by systems and states to quickly identify potential simultaneous compliance issues.

- Exhibit 2.1 (page 2-2) is a **checklist** that can be used to quickly identify potential operational and simultaneous compliance issues. It may be particularly useful for small systems or systems with limited resources.

- Exhibit 2.2 (starting on page 2-3) provides a summary of how different compliance technologies may affect **water quality**. For example, while switching from chlorine to UV will increase CT for *Cryptosporidium*, it may decrease CT for viruses.

- Exhibit 2.3 (starting on page 2-6) **summarizes simultaneous compliance issues** for individual LT2ESWTR and Stage 2 DBPR compliance technologies. For some treatment strategies listed, no significant impact on drinking water regulations is anticipated. Systems may, however, encounter other challenges, such as an increase in waste residuals or a reduction in the quantity of treated water that can be produced.

- Exhibit 2.4 (starting on page 2-12) identifies potential **operational issues** for individual LT2ESWTR and Stage 2 DBPR compliance technologies.

- Exhibit 2.5 (starting on page 2-13) provides summary information on each of the **case studies** in Appendix B. The case studies give real-world examples of how systems have dealt with simultaneous compliance issues with past regulations and in anticipation of the Stage 2 DBPR and LT2ESWTR.

- Exhibit 2.6 (page 2-16) lists **tools** that can be used to gather more information on how a system may be affected by a treatment change.

1   **Exhibit 2.1 Checklist for Identifying Key Operational and Simultaneous Compliance Issues**
2
3   If you are considering a treatment modification or a new treatment to meet the LT2ESWTR or Stage 2 DBPR, this checklist can help
4   you see if you might have problems complying with other drinking water regulations. If you answer "yes" to any of these questions,
5   go to the section in Chapter 3, 4, or 5 that addresses your treatment change. There you will find a list of potential simultaneous
6   compliance issues, suggestions for how to address them, and other helpful information.
7

Yes   No

☐   ☐   ***Will you be getting less CT as a result of the treatment change?*** If you answered "yes" and are a surface water system, you must conduct disinfection profiling.

☐   ☐   ***Will the treatment change cause an increase (seasonal or permanent) in organic carbon?*** If yes, you could potentially have problems complying with the Stage 1 DBPR, the Stage 2 DBPR, or the TCR.

☐   ☐   ***Will the treatment change reduce the pH and/or alkalinity of your finished water***? If yes, your finished water could be more corrosive and you could have problems complying with the LCR.

☐   ☐   ***Will you be using a different residual disinfectant?*** Disinfectant residual changes can impact TCR and LCR compliance.

☐   ☐   ***Will the treatment change affect the quality of water being filtered?*** A change in coagulation or pre-disinfection could affect filter performance and compliance with the LT1ESWTR or IESWTR.

☐   ☐   ***Will the treatment change result in higher or lower concentrations of inorganics, such as manganese, iron, aluminum, sulfate, chloride, or sodium in your finished water?*** If yes, your water could become more corrosive and you could have problems complying with the LCR. You could also have aesthetic problems.

☐   ☐   ***Will the treatment change cause an increase in production of waste residuals (e.g., enhanced coagulation could cause your system to produce more sludge)?*** This is not typically a compliance issue, but increased residual production can present operational challenges for your system.

8

1
2

Exhibit 2.2 Technology Alternatives and How They Potentially Affect Water Quality

	CT	pH	alkalinity	disinfectant residual[1]	iron or manganese	turbidity	NOM	DBPs	corrosivity	AOC	taste and odor
Source Management[2]	may decrease if colder water is used	may increase or decrease	may increase or decrease		may increase		may decrease	may decrease	may increase or decrease		may increase
Distribution System BMPs				may increase		may increase if flushing not done properly		TTHM may decrease; HAA5 may decrease or increase	may decrease		may increase
Moving the Point of Chlorination Downstream	may decrease			may increase or decrease	may increase			decrease			
Decreasing pH	increase	decrease	may decrease					TTHM may decrease, HAA5 may increase	may increase		
Reducing Chlorine Dose Under Warmer Water Conditions	may decrease	may increase or decrease		may decrease				decrease			
Presedimentation					may decrease	may decrease	may decrease	may decrease			
Enhanced Coagulation	may increase	decrease	may decrease		manganese may increase	may increase or decrease	decrease	decrease	may increase		

	CT	**pH**	**alkalinity**	**disinfectant residual[1]**	**iron or manganese**	**turbidity**	**NOM**	**DBPs**	**corrosivity**	**AOC**	**taste and odor**
Softening/ Enhanced Softening	may increase, may decrease due to high pH	increase	may increase		may decrease	may decrease	may decrease	HAA5 may decrease, TTHM may increase	concrete corrosion may increase		
GAC					may increase due to GAC fines	decrease	decrease	decrease		may decrease if GAC is biologically active	decrease
Microfiltration/ Ultrafiltration					may decrease	decrease		may decrease			
Nanofiltration		may decrease	may decrease		decrease	decrease	may decrease	decrease	increase	may decrease	
Bank Filtration					may increase						
Bag Filtration					may decrease	may decrease					
Cartridge Filtration					may decrease	may decrease					
Second Stage Filtration					may decrease	decrease	may decrease	may decrease		may decrease	
Slow Sand Filtration					may decrease	may decrease	may decrease	may decrease			
DE Filtration					may decrease	may decrease					
Improved Filter Performance					may decrease	decrease	may decrease	may decrease			
Chloramines[3]	decrease			may increase				TTHM and HAA5 will decrease	may increase or decrease		may increase or decrease

	CT	pH	alkalinity	disinfectant residual[1]	iron or manganese	turbidity	NOM	DBPs	corrosivity	AOC	taste and odor
Ozone[3]	increase for protozoa							may decrease, but increase in bromate	may increase or decrease		may increase or decrease
UV Disinfection[3]	UV dose is low for protozoa, need higher dose for viruses							decrease			
Chlorine Dioxide[3]	increase for protozoa, decrease for viruses				may decrease if followed by filtration			TTHM and HAA5 decrease, chlorite will be formed			may increase or decrease

1   [1] Refers to the disinfectant residual in distribution system water.
2   [2] For the purpose of this guidance, *source management* refers to techniques water systems can use to manipulate their water sources to comply
3   with Stage 2 DBPR or LT2ESWTR regulations. In this context, source management does not refer to source water protection or other long-term
4   watershed efforts to improve water quality. The source management techniques discussed in this section are operational changes made by
5   water systems to use the source with the least amount of natural organic matter (NOM), or selecting a blend of sources to try to achieve the
6   most effective treatment for organics and turbidity removal. Source management strategies can affect raw water quality or they can affect
7   finished water quality directly (e.g., blending or alternating sources).
8   [3] Water quality changes for alternative disinfectants are compared to conditions when free chlorine is used.
9

1
2
3

**Exhibit 2.3 Stage 2 DBPR and LT2ESWTR Compliance Technologies:
Summary of Benefits and Potential Conflicts**

System Modification / Compliance Technology	Used for Compliance with		Potential Benefits	Potential Issues		
	Stage 2 DBPR	LT2ESWTR		Description	SDWA Rule(s) of Concern	Where It's Discussed in More Detail
Source Management	X	X	• may reduce DBP precursors • may reduce disinfectant demand • can improve treatability of raw water for turbidity and/or DBP precursor removal	• water temperature change may affect CT and coagulation/flocculation • may introduce new contaminants (e.g. iron, manganese, sulfide) • raw water pH change can adversely affect water treatment and/or corrosion control • may increase coagulant demand • may increase disinfectant demand	SWTR, Stage 1 D/DBPR, Stage 2 DBPR, IESWTR, LT1ESWTR, LCR.	Section 3.1
Distribution System BMPs	X		• targets specific problem areas • can improve microbial control • reduces DBPs • can reduce corrosion	• can stir up sediments • issues with disposal of chlorinated water • lining materials leaching into water • less storage available for emergencies, increased water loss	TCR, Stage 1 D/DBPR, Stage 2 DBPR.	Section 3.2
Moving the Point of Chlorination Downstream	X		• reduces DBP concentrations • reduces amount of disinfectant used • can facilitate monthly total organic carbon (TOC) source water monitoring	• may reduce CT • increases chances of filter fouling • may impact taste and odor control • may reduce Asiatic clam or zebra mussel control • provides less effective treatment for iron or manganese • may require adjustment of water treatment chemistry • may need to increase disinfectant dosage, which could produce more DBPs	IESWTR, LT1ESWTR, LT2ESWTR, Stage 1 D/DBPR.	Section 3.3

4
5
6

System Modification / Compliance Technology	Used for Compliance with		Potential Benefits	Potential Issues		
	Stage 2 DBPR	LT2ESWTR		Description	Rule(s) of Concern	Where It's Discussed in More Detail
Decreasing pH	X		• same CT can be achieved with lower disinfectant dose • lower pH may reduce some DBPs	• may increase HAA5 • may impact ability to filter • can cause corrosion problems • can adversely affect treatment plant equipment • may impact settling and sludge dewatering • solubility of inorganics may increase • varying pH can create changes in distribution system surfaces	Stage 1 D/DBPR, Stage 2 DBPR, IESWTR, LT1ESWTR, LCR.	Section 3.4
Modifying Chlorine Dose Under Different Temperature Conditions	X		• lower chlorine dose needed for microbial protection in warm water • lower chlorine dose when DBP formation rates may be high	• pathogen concentrations may be higher when water is warm (e.g., recreational waters) • less disinfection when coliform incidents are more common in distribution systems • systems may have trouble maintaining required inactivation	IESWTR, LT1ESWTR, TCR, SWTR.	Section 3.5
Presedimentation		X	• removes *Cryptosporidium* • can remove DBP precursors	• algal growth in basins can increase DBP precursors • removal of solids difficult	Stage 1 D/DBPR, Stage 2 DBPR.	Section 3.6
Enhanced Coagulation	X		• decreases TTHM and HAA5 • may improve disinfection effectiveness • can reduce bromate formation • can reduce chloroform formation • can enhance arsenic and radionuclide removal	• may adversely impact finished water turbidity • lower pH can cause corrosion problems • may see increased inorganics concentrations in finished water • can impact *Cryptosporidium* removal • systems may have issues with disposal of additional residuals • systems may have issues with disposal of residuals with high levels of radioactivity	IESWTR, LT1ESWTR, LCR, FBRR.	Section 3.7

1

2

3

4

System Modification / Compliance Technology	Used for Compliance with		Potential Benefits	Potential Issues		Where It's Discussed in More Detail
	Stage 2 DBPR	LT2ESWTR		Description	Rule(s) of Concern	
Softening/ Enhanced Softening	X	X	• removes DBP precursors • lowers HAA5 • increases effectiveness of chloramines • two stage plants can achieve *Cryptosporidium* removal credit • high calcium sludges may de-water more easily	• lower chlorine effectiveness at high pH • may cause aluminum carryover • may increase scaling in treatment plant and distribution system piping • higher TTHM formation at high pH • need to lower pH before ozonation • prechlorination may reduce TOC removal • increased process residuals • increased concrete corrosion	SWTR, IESWTR, LT1ESWTR, LT2ESWTR, Stage 1 D/DBPR.	Section 3.8
Granular Activated Carbon (GAC)	X	X	• removes DBP precursors • removes taste and odor compounds • if used as secondary filter, removes *Cryptosporidium* • removes AOC after ozone when used as biological filter	• may release previously adsorbed compounds • precursor removal may be limited by type of TOC • bacteria can be released • fines can foul downstream processes at startup • water with disinfectant residual should not pass through • ammonia added before GAC may increase nitrification	TCR, IESWTR, LT1ESWTR.	Section 4.1
Microfiltration/ Ultrafiltration		X	• removes bacteria and protozoa • decreases turbidity • can lower DBPs by allowing lower disinfectant doses	• pore size will not reliably remove DBP precursors or viruses • although bacteria and protozoa are removed, system must still provide disinfectant residual • may have increased loss of process water	SWTR.	Section 4.2

1
2
3
4

1

System Modification / Compliance Technology	Used for Compliance with		Potential Benefits	Potential Issues		Where It's Discussed in More Detail
	Stage 2 DBPR	LT2ESWTR		Description	Rule(s) of Concern	
Nanofiltration	X	X	• removes microbial pathogens • can remove DBP precursors	• produces corrosive water • although microbes are removed, system must still provide a disinfectant residual • can lower pH • increased loss of process water	SWTR, LCR.	Section 4.3
Watershed Control Program	X	X	• reduces microbial risk • reduces DBP precursor loading • reduces chemical contamination	• none known	None known	Not discussed
Bank Filtration		X	• increases pathogen removal • decreases turbidity • decreases DBP precursors	• hydraulic issues • iron/manganese problems	None known	Section 4.4
Bag Filtration		X	• reduces microbial risk	• hydraulic issues	None known	Section 4.4
Cartridge Filtration		X	• reduces microbial risk	• hydraulic issues • disposal issues	None known	Section 4.4
Second Stage Filtration	X	X	• reduces particulate matter • reduces DBPs and DBP precursors • reduces microbial risk • reduces assimilable organic carbon (AOC)	• hydraulic issues • increased residuals	None known	Section 4.4
Slow Sand Filtration		X	• reduces microbial risk • may reduce DBP precursors • may improve disinfection effectiveness	• hydraulic issues	None known	Section 4.4

2

1

System Modification / Compliance Technology	Used for Compliance with		Potential Benefits	Potential Issues		
	Stage 2 DBPR	LT2ESWTR		Description	Rule(s) of Concern	Where It's Discussed in More Detail
Diatomaceous Earth (DE) Filtration		X	• reduces microbial risk	• hydraulic issues	None known	Section 4.4
Improved Filter Performance		X	• reduces microbial risk • reduces chemical contaminants • improves disinfection effectiveness • improves aesthetic quality	• increased residuals • disposal issues	None known	Section 4.4
Chloramines	X		• reduce DBPs • may improve biofilm control • may increase ability to maintain disinfectant residual throughout distribution system • minimal impact on water treatment plant process • relatively easy to install and operate • may improve taste and odor	• nitrification may occur in distribution system • may cause corrosion problems with some materials • potential taste and odor problems if improper ratio is used • less help eliminating some taste and odor compounds • can be difficult to blend with other chlorinated sources • weaker disinfectant, increases required CT • ozone and GAC can lead to faster residual decay • issues for dialysis patients, fish owners and industrial users.	TCR, IESWTR, SWTR, LCR.	Section 5.1
Ozone	X	X	• Inactivates *Cryptosporidium* and *Giardia* • does not form TTHM or HAA5 • effective pre-oxidant • raises UV transmittance of water • may aid coagulation • can help taste and odor problems	• forms bromate • forms AOC • does not provide a residual • can cause taste and odor problems • can cause corrosion problems • ozone bubbles can hinder filter performance if not operated properly	Stage 1 D/DBPR, TCR, SWTR, LCR, IESWTR, LT1ESWTR.	Section 5.2

2

3

4
5

1

2

3

| System Modification / Compliance Technology | Used for Compliance with | | Potential Benefits | Potential Issues | | Where It's Discussed in More Detail |
	Stage 2 DBPR	LT2ESWTR		Description	Rule(s) of Concern	
Ultraviolet (UV) Disinfection	X	X	• inactivates *Cryptosporidium* and *Giardia* • does not produce regulated DBPs • effectiveness not pH or temperature dependent	• need higher light intensities to inactivate viruses • does not provide a residual	SWTR, IESWTR, LT1ESWTR.	Section 5.3
Chlorine Dioxide	X	X	• achieves some *Cryptosporidium* inactivation • less TTHM and HAA5 formation than with chlorine • can work well for taste and odor control • oxidizes iron and manganese	• forms chlorite • reduced effectiveness at low temperatures • may be challenged by chlorine dioxide Maximum Residual Disinfectant Level (MRDL) • can form brominated DBPs • degrades under UV light • potential odor problems	Stage 1 D/DBPR, SWTR, IESWTR, LT1ESWTR.	Section 5.4

Exhibit 2.4 Potential Operational Issues for Different Treatment Modifications

Topic is marked with an "X" if it may be a concern for the treatment modification — Treatment Modification	Production Capability	Compatibility with Treatment Facilities	Residual/Disposal Issues	Site Specific Issues	Distribution System Materials	Distribution System Operations	Environmental Issues	Consumer Driven Issues	Preference of Operation Staff	Consecutive System Requirements	Costs[1]	Where it's discussed in more detail
Source Management	X	X	X	X	X	X	X	X		X		Section 3.1
Distribution System BMPs					X	X	X	X	X	X	X	Section 3.2
Moving Point of Chlorination Downstream		X		X	X			X	X	X		Section 3.3
Decreasing pH		X	X	X	X	X			X	X		Section 3.4
Decreasing Chlorine Dose Under Warm Water Conditions					X	X	X		X	X		Section 3.5
Presedimentation		X	X	X					X	X		Section 3.6
Enhanced Coagulation		X	X	X	X	X	X		X	X		Section 3.7
Softening/Enhanced Softening		X	X	X	X	X			X	X		Section 3.8
Granular Activated Carbon		X	X	X	X	X			X	X	X	Section 4.1
Microfiltration/Ultrafiltration	X	X	X	X			X		X	X	X	Section 4.2
Nanofiltration	X	X	X	X	X	X	X		X	X	X	Section 4.3
Bank Filtration	X			X				X				Section 4.4
Other Microbial Removal Technologies (improved filter performance, bag filtration, cartridge filtration, second stage filtration, slow sand filtration, DE filtration)	X	X	X	X					X		X	Section 4.4
Chloramines					X	X	X	X	X	X		Section 5.1
Ozone		X			X	X	X		X	X	X	Section 5.2
UV Disinfection	X	X		X					X	X	X	Section 5.3
Chlorine Dioxide					X	X	X		X	X	X	Section 5.4

1. It is important to note that costs are associated with any modification or new treatment. This column is meant to identify changes that are generally more costly compared to others. Also note that some distribution system BMPs, such as looping dead end pipes, can have relatively high costs.

1
2

2. Exhibit 2.5 Case Studies in this Guidance Manual and Issues they Address

Case Study No.	Treatment/Issue Addressed	Utility Name	Case Study Location	Population Served	Average Annual Treatment Plant (MGD) Production	Source Water	Page	Section Where It is Referenced in the Manual
1	Moving the Point of Chlorination Downstream	Owenton Water Works and Kentucky American TriVillage	Owenton, Kentucky	<10,000	1	Surface Water (reservoir)	B-7	3.3
2	Decreasing pH	Public Utility District #1	Skagit County, Washington	70,000	12	Surface Water (reservoir)	B-13	3.4
3	Presedimentation	Kansas City Water Services	Kansas City, Missouri	>600,000	240	Surface Water (river, ground water under the direct influence of surface water)	B-21	3.6
4	Switching Coagulants	Hillsborough River Water Treatment Plant	Tampa, Florida	>450,000	100	Surface Water (river)	B-25	3.7
5	Enhanced Coagulation - Problems with Copper Pitting	Washington Suburban Sanitary Commission	Montgomery and Prince Georges County, Maryland	1,600,000	167	Surface Water (rivers)	B-33	3.7

Case Study No.	Treatment/Issue Addressed	Utility Name	Case Study Location	Population Served	Average Annual Treatment Plant (MGD) Production	Source Water	Page	Section Where It is Referenced in the Manual
6	Enhanced Coagulation - Managing Radioactive Residuals	Allen Water Filtration Plant	Englewood, Colorado	48,000	8.5	Surface Water (river, creek, diversions)	B-39	3.7
7	GAC for TOC Removal	Higginsville Water Treatment Plant	Higginsville, Missouri	<10,000	2	Surface Water (reservoir)	B-45	4.1
8	Nanofiltration Membrane Technology for TOC Removal	PBCWUD Water Treatment Plant #9	West Palm Beach, Florida	132,000	27	Surface Water (surficial aquifer)	B-49	4.3
9	Modifying Chloramination Practices to Address Nitrification Issues	Ann Arbor Utilities	Ann Arbor, Michigan	115,000	20	Surface Water (river, wells)	B-57	5.1
10	Ozonation	Ann Arbor Utilities	Ann Arbor, Michigan	115,000	20	Surface Water (river, wells)	B-63	5.2
11	Ozonation and Biological Filtration	Sweeney Water Treatment Plant	Wilmington, North Carolina	75,000	25	Surface Water (river)	B-71	5.2

Case Study No.	Treatment/Issue Addressed	Utility Name	Case Study Location	Population Served	Average Annual Treatment Plant (MGD) Production	Source Water	Page	Section Where It is Referenced in the Manual
12	UV Disinfection	Poughkeepsie Water Treatment Facility	Poughkeepsie, New York	75,000	16	Surface Water (river)	B-77	5.3
13	Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection	Gulf Coast Water Authority	Texas City, Texas	92,000	12	Surface Water (river)	B-81	5.4
14	Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection	Village of Waterloo Water Treatment Plant	Waterloo, New York	<10,000	2	Surface Water (lake)	B-89	5.5

1
2

1
2
3

Exhibit 2.6 Tools for Gathering System-Specific Information on Different Treatment Technologies

Compliance Techniques	Water Quality Monitoring	Hydraulic and WQ Modeling for DS	Desktop Evaluation	Bench-Scale: Disinfectant Demand and Decay	Bench-Scale: DBP Formation and Decay	Bench-Scale: Taste and Odor Profiles	Bench-Scale: Jar/Column Testing Procedures	Bench-Scale: Internal Corrosion Assessment	Pilot Testing	Full Scale Applications	Cost Estimation	Community Preferences	Where it's discussed in more detail
Source Management	X						X						Section 3.1
Distribution System BMPs	X	X							X				Section 3.2
Moving the Point of Chlorination Downstream	X					X	X		X				Section 3.3
Decreasing pH	X						X	X	X				Section 3.4
Decreasing Chlorine Dose Under Warm Water Conditions	X			X	X								Section 3.5
Presedimentation			X										Section 3.6
Enhanced Coagulation			X				X	X	X				Section 3.7
Softening/Enhanced Softening			X			X	X	X	X				Section 3.8
GAC			X				X			X	X		Section 4.1
Microfiltration/Ultrafiltration									X	X	X		Section 4.2
Nanofiltration								X	X	X	X		Section 4.3
Bank Filtration									X	X	X		Section 4.4
Chloramines	X			X	X	X		X	X			X	Section 5.1
Ozone	X			X	X	X		X			X	X	Section 5.2
UV Disinfection									X	X	X		Section 5.3
Chlorine Dioxide	X			X	X	X		X				X	Section 5.4

4

<div style="border: 2px solid black;">

3 Improving and Optimizing Current Operations

</div>

Public water systems (PWSs) may want to consider whether they can modify their source water management, treatment processes, or distribution system operations before taking on the challenge of installing a new treatment technology to meet the requirements of the Stage 2 DBPR and LT2ESWTR. This chapter addresses ways that water systems might change how they operate their existing facilities to achieve compliance with the Stage 2 DBPR and LT2ESWTR, and potential simultaneous compliance challenges that can arise when such operational changes are made.

> **OPERATIONAL PRACTICES COVERED IN THIS CHAPTER**
>
> - Source Management
> - Distribution System Best Management Practices
> - Moving Point of Chlorination
> - Modifying pH During Chlorination
> - Modifying Chlorine Dose Under Different Temperature Conditions
> - Modifying Presedimentation Basin Operations
> - Enhanced Coagulation
> - Enhanced Softening

Several of the sections in this chapter address ways that water systems may change how they chlorinate. Before making any changes to disinfection practices, systems that are required to develop a disinfection profile must calculate a disinfection benchmark for the treatment configuration currently in place. To learn more about disinfection profiling and benchmarking, refer to EPA's *Disinfection Profiling and Benchmarking Guidance Manual* (1999a).

3.1   Source Management

For the purpose of this guidance, the term *source management* refers to techniques that water systems can use to manipulate their water source or sources to comply with Stage 2 DBPR or LT2ESWTR regulations. In this context, source management does not refer to source water protection or other long-term watershed efforts to improve water quality. The source management techniques discussed in this section are operational changes made by water systems to use the source with the least amount of natural organic matter (NOM), or selecting a blend of sources to try to achieve the most effective treatment for organics and turbidity removal.

Examples of source management include:

- Selecting the optimum depth from which to draw water. Systems using lake or reservoir sources should have multi-level intakes. This flexibility allows the system to draw water from different depths or locations, depending on the source water quality during that time of year or for other reasons (e.g. algal bloom, storm upsets, etc).

> Water system managers should check with their primacy agency before making any source management changes. Approval of the primacy agency may be required before a water system modifies or switches its raw water source.

- Blending various sources. Systems that have multiple sources may consider blending surface and ground water sources to attain the best blended raw water for compliance.

- Alternating between sources. Systems with multiple sources may consider alternating between surface water and ground water sources depending on source water quality at a given time. Systems may also temporarily discontinue use of a source for a period of time when impacts are expected or water quality is poor.

Source management may be considered a temporary, seasonal, or permanent solution depending on physical or chemical characteristics of the source; the need to reduce disinfection byproduct (DBP) precursors and/or turbidity; the availability of alternate, additional, or new sources; and the impact the water chemistry change has on the rest of the system. For example, a system may only have seasonal issues with DBP precursor concentrations and, therefore, may decide to apply one or more source management techniques on a seasonal basis.

Many factors can have a temporary or seasonal impact on surface water quality and can impact organic loading, turbidity, and pathogen concentrations entering the plant. If these impacts are understood and flexibility is built into the plant intake and operations, the system may be able to use source management strategies to avoid or mitigate simultaneous compliance issues. These factors include:

- Seasonal turnover - In colder climates many reservoirs and lakes experience turnover during the spring and fall. When this occurs, sediment and organic matter at the bottom of the reservoir can be stirred up and re-suspended. This can lead to an increase in organic load, algal blooms causing taste and odor, turbidity, and higher pathogen concentrations entering the plant.

1   • Precipitation events - Heavy rainfall or snowmelt can wash organic matter from soils
2   into surface water sources. A runoff event upstream of the intake can result in an
3   increase in organic load and pathogens entering the plant.
4
5   • Algae blooms - Seasonal algae blooms that occur in lakes and reservoirs can impact
6   NOM levels and raw water pH in water nearer to the surface. Decayed algae can
7   contribute organics to sediment that later become problematic during turnover. Algal
8   blooms can also interfere with filter operation and may interfere with analysis for
9   *Cryptosporidium* and *Giardia*.
10
11   • Point source discharges - Discharges from wastewater treatment plants, water
12   treatment plants, and industrial discharges upstream of the intake can increase the
13   organic load and pathogens in source water. This becomes more significant when
14   stream flow decreases and there is less dilution.
15
16   • Nonpoint sources of pollution - Nonpoint discharges of pollution can impact the
17   organic load in the source water. They can also increase microbial contaminants such
18   as *Cryptosporidium* and increase nutrients that can cause algal blooms. Many such
19   sources of pollution are intermittent or seasonal and, if the system is aware in
20   advance, adverse impacts can be avoided by temporarily discontinuing use of the
21   source.
22
23   If a ground water is used to supplement a surface water source on a seasonal basis, the quality of
24   the ground water needs to be considered, including its pH, iron and manganese concentrations,
25   oxidation reduction (redox) potential of the water, and any nearby contaminant plumes.
26
28   While changes to the source may be
30   advantageous for minimizing DBP precursor
32   concentrations or turbidity, any major changes in the
34   source water entering plants are likely to be
36   accompanied by corresponding changes in other raw
37   water chemistry. These may include changes in pH, temperature, alkalinity, organics,
38   inorganics, radionuclides, etc. As a result, these changes will have an impact on the treatment
39   processes employed by the system and may impact the distribution system as well. Therefore,
40   when a source water change is considered, water quality monitoring and jar testing should be
41   conducted to determine the impacts the change in water chemistry will have on the plant, as well
42   as the stability of the distribution system.
43
44

> Jar testing should be conducted when a system is considering a source water change.

1   **3.1.1   Advantages of Source Management**
2
3   By using source management techniques, a PWS may be able to:
4
5   • **Reduce DBP precursors in the raw water (reduction in raw water organic load)**
6
7   • **Reduce amount of disinfectant used**
8
9   • **Improve treatability of raw water for turbidity and/or DBP precursors**
10
11   *Reduce DBPs*
12
13   Selecting a source water or combination of

> Routine reservoir monitoring can help a system select the best intake depth for minimizing DBPs.

14   source waters containing the least amount of
15   organic matter can reduce finished water DBP
16   concentrations. The water chemistry of stratified
17   lakes and reservoirs can change seasonally and vary significantly depending on water depth.
18   Different depths in a stratified source may contain different concentrations of organics with
19   different characteristics (e.g., particulate vs. dissolved, high vs. low molecular weight). Water
20   systems can use this to their advantage by determining the depth containing the lowest DBP
21   precursor concentrations or precursors that are most easily removed, and then draw their source
22   water from this depth. Systems should keep in mind, however, that the depth producing the
23   lowest concentration of DBP precursors may change seasonally. It is important for an effective
24   source management program to include routine monitoring to detect changes in water quality at
25   different intake depths and guide decision-making. Section 3.1.3 provides some suggestions for
26   additional monitoring that can help in this way.
27
28   Blending sources can also produce lower finished water DBP concentrations if the
29   additional source used in blending contains lower concentrations of DBP precursors.
30
31   *Reduce Amount of Disinfectant Used*
32
33   Organic matter, inorganic matter, and biota such as algae in water usually present a
34   chlorine demand. If an alternative water source is used that is well-oxygenated and has lower
35   concentrations of organic matter, iron, and manganese, that water is likely to have a lower
36   chlorine demand than the poorer quality water previously used.
37
38   *Raw Water Treatability*
39
40   By drawing water from different depths in a stratified source, blending sources or
41   alternating sources, the raw water chemistry may also be manipulated to provide optimum
42   conditions for water treatability resulting in increased particulate removal. For example, systems

1   that have minimal alkalinity in the source water may find that blending another source water
2   with higher alkalinity will improve coagulation (when using alkalinity-dependent coagulants),
3   resulting in a reduction in DBP precursors and turbidity. In this situation, however, water
4   systems should keep in mind that increasing alkalinity would in turn increase the amount of
5   chemical needed to lower the pH and effectively remove total organic carbon (TOC).
6
7   Different types of organic matter in water can be removed more or less effectively during
8   coagulation. In general, water containing primarily non-humic organic matter is less amenable
9   to enhanced coagulation. This type of water is also more likely to have a lower specific
10   ultraviolet absorbance (SUVA) concentration. By monitoring for NOM indicators such as
11   SUVA in their source water alternatives, water systems can pick the water that can be treated
12   more effectively for NOM removal and, possibly, reduce DBP concentrations in the finished
13   water.
14
15   By avoiding water with algal blooms, systems can improve the coagulation properties of
16   the water. Avoiding algal blooms can also reduce taste and odors compounds, which are
17   difficult to remove during conventional treatment.
18
19   **3.1.2   Potential Operational and Simultaneous Compliance Issues Associated with Source**
20   **Management Changes**
21
22   Any changes to the raw water as a result of source management are likely to affect the
23   raw water chemistry and in some way impact treatment processes. While the goal may be to
24   minimize organic loading or provide optimum conditions for DBP precursor and turbidity
25   removal, adverse changes in the raw water chemistry may include:
26
27   •   **Water temperature changes affecting CT calculations and coagulation and**
28   **flocculation**
29
30   •   **Introduction of new contaminants or higher concentrations of existing**
31   **contaminants (e.g., iron, manganese, sulfide)**
32
33   •   **Variation in raw water pH adversely affecting water treatment**
34
35   •   **Reduction in coagulation effectiveness through other chemistry changes or**
36   **increased coagulant demand (e.g., alkalinity, type of turbidity)**
37
38   •   **Increased disinfectant demand for water under reduced conditions (e.g., little or**
39   **no dissolved oxygen)**
40
41   •   **Changes in aesthetic quality may generate customer complaints**
42

1   General suggestions for addressing some of these issues that may arise as a result of source
2   changes are provided below.
3
4   *Changes in Water Temperature*
5
6   If a water system's managers opt to draw from a lower level in a thermally stratified
7   reservoir during warmer months in order to decrease DBP precursors at the plant, the water
8   temperature may be considerably lower than the system typically experiences. It is not unusual
9   in northern parts of the U.S. for water temperatures near the top of a reservoir to be at least 10
10   degrees C higher than temperatures near the bottom. As water temperature decreases, pathogen
11   inactivation using most disinfectants is less effective, and therefore the required CT must be
12   increased. Since the system's contact time (T) is generally set, the disinfectant concentration (C)
13   may need to be increased when operating at maximum capacity. Therefore, the benefit gained
14   by changing the source to one with lower DBP precursors may be offset by the required increase
15   in disinfectant concentration, and little gain in terms of reducing finished water DBPs may be
16   realized. Alternatively, the lower temperature may slow down DBP formation reactions and
17   residual decay reactions that may mitigate the effect of temperature to some degree.
18
19   The converse, however, may also apply. If a system draws from a higher level in the
20   reservoir and there is a corresponding higher temperature, this may result in more efficient
21   inactivation and therefore less required CT.
22
23   Colder water temperatures also result in slower floc formation in the coagulation process
24   and therefore, decreased efficiency of turbidity removal (Faust and Aly 1998).
25
26   <u>Recommendations for Addressing this Issue</u>
27
28   Systems may need to increase their CT when using a colder water source. Frequently a
29   system's T is set, especially when a system is operating at maximum capacity in the summer
30   months. Therefore, the disinfectant concentration (C) may need to be increased.
31
32   Changes in temperature may require changes in coagulant dose, mixing speeds, and other
33   factors related to coagulation. To determine the impact colder water temperature may have on
34   the coagulation process, systems should conduct jar tests with the modified source water to
35   determine optimum conditions for coagulation based on the new water temperature and
36   chemistry. As the source water temperature and/or water chemistry changes, additional jar tests
37   should be conducted to determine the optimum conditions based on the new temperature or water
38   chemistry change.
39
40   *Introducing New Contaminants or Higher Concentrations of Existing Contaminants*
41
42   Contaminants such as arsenic, dissolved iron, dissolved manganese, or hydrogen sulfide
43   may be introduced or their concentrations may be increased depending on source management

1   decisions. For example, in the summer months a system may alternate its surface water source
2   with a ground water source to produce water lower in DBPs. This may, however, introduce
3   contaminants into the source water for which there is not adequate treatment in place for
4   removal, or the contaminant may deplete chemicals used in the treatment process that are needed
5   for other purposes (e.g., dissolved iron may deplete chlorine meant to be used for disinfection).
6   For systems using thermally stratified sources, drawing from a lower depth to avoid high
7   turbidities may introduce water with higher concentrations of dissolved organics or soluble
8   metals.
9
10   Another potential problem with a system introducing new contaminants or contaminants
11   at higher concentrations is the potential for increasing contaminant concentrations in the residual
12   waste streams of certain treatment processes. For example, if higher arsenic concentrations are
13   introduced in a surface water plant, the arsenic will be oxidized and removed, and will be
14   concentrated in the sludge and backwash water.
15
16   <u>Recommendations for Addressing this Issue</u>
17
18   To address the problem of introducing or increasing contaminant concentrations in the
19   source water, systems should analyze the water chemistry of the alternate source for typical
20   constituents and suspected contaminants. Systems can then compare the alternate source's water
21   chemistry with the original source and consider the possible impacts prior to making source
22   changes. Section 3.1.3 provides some suggestions for additional monitoring to assist with this
23   decision making process. Once the new source water chemistry has been characterized, systems
24   using coagulants should conduct jar tests to determine if contaminant concentrations negatively
25   impact the treatment process. Several tests may be necessary to determine a source management
26   option that works best in terms of meeting all treatment goals.
27
28   *Problems with a Change in Raw Water pH*
29
30   A water system may change its source to decrease DBP precursors at the plant, but the
31   change may also affect the pH of the raw water. Variations in raw water pH will affect CT,
32   coagulation effectiveness for certain coagulants, and possibly DBP formation, unless pH is
33   controlled ahead of and through the treatment plant.
34
35   For systems that use chlorine to disinfect, pathogen inactivation is very dependent on pH.
36   As pH increases, inactivation is less efficient, and therefore the required CT must be increased.
37   Since the system's contact time is set, the disinfectant concentration (C) may need to be
38   increased when operating at maximum flow. As with the impact from temperature, the benefit
39   gained by changing the source to one with lower precursors may be offset by the required
40   increase in disinfectant concentration. Under these circumstances, little gain may be realized.
41
42   Variations in the raw water pH can affect the coagulation process. The pH may no longer
43   be in the optimum range for coagulation using pH-dependent coagulants such as alum. Less

1 effective coagulation is likely to result in less DBP precursor removal, leaving more DBP
2 precursors available for reaction with chlorine or other disinfectants downstream in the treatment
3 process. If the pH of the source water is low and alum is used for coagulation, aluminum ions
4 may pass through the filters if alum is overdosed. If the pH is raised for corrosion control before
5 the water reaches the distribution system, the aluminum ions that passed through the filters will
6 then precipitate, causing the water to appear turbid.
7
8   Recommendations for Addressing this Issue
9
10   If the source water pH changes, water systems should conduct jar tests to determine
11 optimum treatment conditions based on the new pH. Systems should ensure that corrosion
12 control is adjusted accordingly if the pH change persists in water entering the distribution
13 system.
14
15 *Reduced Coagulant Effectiveness*
16
17   If source management is used to reduce DBP precursors, the turbidity of the raw water
18 may increase or decrease as a result. An increase in turbidity may require an increased
19 coagulation chemical demand as well as alkalinity demand depending on the coagulant used.
20 Water with increased turbidity may be more difficult to treat, especially for systems that are not
21 optimized or are nearing the design capacity of the coagulation process. A decrease in turbidity
22 may be a problem if there are not enough particles present for effective coagulation. Fewer
23 particles can be more difficult to coagulate because they do not come into contact as easily with
24 one another to form larger flocs that settle well or can be filtered out effectively. Higher influent
25 turbidity can also lead to higher settled water turbidity and problems with filtration.
26
27   Recommendations for Addressing this Issue
28
29   Systems should characterize the source water chemistry of the proposed new source or
30 blend of sources to ensure there are no negative impacts related to the coagulation process. Jar
31 tests should be performed if parameters that impact coagulation such as turbidity, alkalinity, pH,
32 or temperature change significantly.
33
34 *Increased Disinfectant Demand for Waters under Reduced Conditions*
35
36   When drawing from lower reservoir depths or from ground water sources, the water may
37 be under reduced conditions (with low or no dissolved oxygen (DO)). Dissolved iron,
38 manganese, and hydrogen sulfide may be present in these waters. These reducing agents are
39 readily oxidized by disinfectants and, therefore, increase the disinfectant demand. In addition,
40 dissolved iron and manganese precipitate when oxidized, creating more turbid water and
41 increasing the particle load onto the filters.
42

1   Recommendations for Addressing this Issue
2
3   Water systems should be aware of the DO concentration and oxidation reduction
4   potential of the source water they are using. Chlorine dose should be adjusted to accommodate
5   the increased chlorine demand due to reduced conditions. Alternatively, systems may consider
6   periodic use of an additional oxidant, such as potassium permanganate, to oxidize reduced iron,
7   manganese, or sulfide (Cooke and Kennedy, 2001). Aerating the water before it is treated can be
8   another effective way to eliminate reduced conditions.
9
10   Once they are oxidized, the inorganic chemicals that were formerly dissolved are likely to
11 precipitate. Water systems should carefully review their filter effluent turbidities to ensure that
12 additional particle loading onto the filters is not stressing them. Systems should also conduct jar
13 tests to determine how to adjust their coagulant dose to improve removal of the additional
14 particle load.
15
16 *Changes in Aesthetic Quality May Generate Customer Complaints*
17
18   When drawing from lower reservoir depths or changing to a groundwater source, systems
19 may draw in hydrogen sulfide, iron, manganese and other compounds that may cause taste and
20 odor problems. An increase in hardness may also generate customer complaints.
21
22   Recommendations for Addressing this Issue
23
24   Systems that draw from anoxic layers in stratified reservoirs or from anoxic groundwater
25 may want to add a pre-oxidant to oxidize compounds such as iron, manganese, and hydrogen
26 sulfide (Cooke and Kennedy, 2001). Changes in hardness should be considered and lowered if
27 they become problematic by blending sources or by softening processes.
28
29 **3.1.3   Recommendations for Gathering More Information**
30
31 *See Additional References*
32
33   Readers can turn to Section 7.1.4 in Chapter 7 for technical references associated with
34 source management.
35
36 *Consider Additional Monitoring*
37
38   Source management changes are likely to affect raw water chemistry. Additional
39 monitoring can help systems understand how treatment processes and other components of a
40 PWS will be affected by changes in the raw water chemistry. Water quality monitoring can also
41 be used for making source management decisions. For example, a system that monitors water
42 quality at its various intake depths can use measurements such as turbidity or TOC to decide

which intake gates to open and use. Many of these parameters can be monitored in real time to provide immediate feedback into plant operation.

Systems choosing to use any of the source management options discussed in this section should consider monitoring the applicable following parameters at a location before water enters the treatment plant:

- ✓ Dissolved Oxygen (DO)
  - ‣Ground water and stratified surface water sources
  - ‣DO profiles of lakes or reservoirs at the intake location using a field meter

- ✓ Temperature
  - ‣All sources
  - ‣Temperature profiles of lakes or reservoirs at the intake location using a field meter

- ✓ pH
  - ‣All sources
  - ‣pH profiles of lakes or reservoirs at the intake location using a field meter

- ✓ Secchi disk depth
  - ‣Lakes and reservoirs to determine water clarity

- ✓ Oxidation-reduction (redox) potential
  - ‣Ground water and stratified surface water sources using a field meter, if possible

- ✓ Turbidity

- ✓ Alkalinity

- ✓ NOM measured as TOC or SUVA

- ✓ Dissolved iron

- ✓ Dissolved manganese

- ✓ Hydrogen sulfide

- ✓ Other chemicals known to be problematic for ground or surface water sources in the area.

- ✓ Chlorophyll *a* and algal counts

1 *Consider Other Tools*

2

3   In addition to water quality monitoring, there are multiple tools available in Chapter 6 to
4 help systems evaluate and improve their current water system in relation to the compliance issues
5 they may face when modifying their operation or treatment practices. For example, the
6 AwwaRF report "Design of Early Warning and Predictive Source-Water Monitoring Systems"
7 (Grayman et al. 2001) provides guidance on the development of source water quality monitoring
8 systems that allow utilities to predict water quality events in the source water.

9

10 Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

11

12

13 **3.2   Distribution System Best Management Practices**

14   Many water quality problems can be addressed by implementing best management
15 practices (BMPs) for the distribution system. Many of these BMPs are directed at minimizing
16 the hydraulic residence time (HRT) of the water in the distribution system. Others are aimed at
17 maintaining appropriate disinfectant residuals while minimizing disinfectant demand.   These
18 BMPs are described in more detail in the *Draft Significant Excursion Guidance Manual* (USEPA
19 2003c), in the AWWARF report, *Guidance Manual for Maintaining Distribution System Water
20 Quality* (Kirmeyer, 2000b), and in the new AWWA publication, *Distribution System Water
21 Quality Challenges in the 21st Century – A Strategic Guide* (AWWA 2005b). While these
22 BMPs can be particularly effective for systems using free chlorine for residual disinfection, they
23 can aid any system.

24

25   BMPs for the distribution system include the following:

26

27   •   Overall strategy to reduce HRT in distribution system

28

29   •   Improving mixing in storage facilities to eliminate stagnant zones

30

31   •   Minimizing the average HRT in finished water storage facilities

32

33   •   Decommissioning excess storage

34

35   •   Minimizing HRT and disinfectant demand in pipes through physical system changes
36   and flushing

37

38   •   Booster disinfection

39

Overall Strategy to Reduce HRT in Distribution System

        As water travels through the distribution system, chlorine continues to react with NOM to form DBPs. In addition to higher DBP concentrations, excessive water age can result in other water quality problems including reduced levels of residual chlorine, reduced effectiveness of chlorine residual through formation of organochlorine compounds, increased microbial activity, nitrification, and taste and odor problems. Water systems should develop an overall strategy to manage the water age in their distribution systems. Water age can be controlled through a variety of techniques including management of finished water storage facilities, flushing of piping in the distribution system, looping of dead-ends, re-routing of water by changing the settings on valves, and using blow-offs to move water. The next several sections provide more detailed steps systems can take as part of this overall strategy.

Improving Mixing in Storage Facilities

        Improving mixing in finished water storage facilities can help eliminate stagnant zones. Old water in stagnant zones can often have very high DBPs and no or low disinfectant residual. This water can be released into the system during periods of high demand. Mixing can be improved by increasing inlet momentum, changing the inlet configuration, increasing the fill time, and by installing mixing devices within the storage facility. Hydraulic experts should be consulted to determine which of these strategies will work for a given tank design and configuration.

Minimizing the Average HRT in Storage Facilities

        Increasing volume turnover reduces the average HRT in finished water storage facilities, thereby reducing DBP formation. This BMP can also reduce disinfectant loss and microbial growth. Turnover can be accomplished by increasing the water level fluctuation or drawdown between fill and draw cycles. Increasing the number of cycles per day may help if the cycles are deep into the facility and not minor fluctuations. Converting tanks to hydraulic plug-flow conditions and eliminating common inlet/outlet configurations can also reduce average HRT.

Decommissioning Excess Storage

        Decommissioning excess storage may also be an appropriate strategy if finished water storage facilities are oversized and not needed for emergency conditions or for maintaining system pressure. Removing excess storage facilities that retain water for long periods can help reduce overall system water age.

Minimizing HRT and Disinfectant Demand in Pipes

        Minimizing the HRT in pipes can help reduce the time available for DBP formation, although it is possible for an increase in HAA5 to occur because of less biological degradation.

1   Reducing HRT can also minimize disinfectant residual loss and allow systems to use a lower
2   overall residual concentration, thereby reducing DBPs. Systems can reduce HRT and
3   disinfectant loss through physical system improvements such as looping dead ends, installing
4   blow-offs, and replacing oversized pipes. These can be expensive, however, and cost prohibitive
5   for some systems. HRT can also be reduced through flushing, particularly if it is targeted at
6   areas with very long residence times.
7
8   Systems can reduce the disinfectant residual demand by replacing, cleaning, or lining cast
9   iron pipes with materials that are less prone to microbial growth or have less potential for
10   consuming oxidants. Chlorine demand can also be reduced through unidirectional flushing
11   programs, aimed at removing sediment and scale from the system that would otherwise exert a
12   disinfectant demand.
13
14   *Booster Disinfection*
15
16   In certain instances, booster disinfection can reduce DBP formation by allowing the
17   disinfectant residual to be lowered at the plant and boosting disinfectant only in those areas
18   where it is necessary to maintain an adequate residual. This BMP can reduce DBPs at the plant
19   and throughout the system.
20
21   **3.2.1   Advantages of Distribution System BMPs**
22
23   The main advantages of distribution system BMPs are that many are relatively cost
24   efficient ways to control DBPs in the distribution system and can be implemented in a short time
25   without the need for major treatment plant improvements. Other advantages to using distribution
26   system BMPs may include:
27
28   • **Target specific problem areas rather than the entire system**
29
30   • **Improve microbial control as well as reduce DBP formation**
31
32   • **Improve chlorine residual maintenance**
33
34   • **Reduce corrosion**
35
36   • **Reduce nitrification**
37

> **Distribution System BMPs can be a relatively cost efficient way to control DBPs in the distribution system.**

38   *Target Specific Problem Areas*
39
40   Many of the BMPs such as flushing, booster disinfection, pipe lining and replacement, and
41   those dealing with finished water storage facilities can target specific problem areas rather than
42   apply a solution to the entire system. This can lead to lower DBPs throughout the system.

1   *Improve Microbial Control*
2
3   In additional to reducing DBP formation, most BMPs will improve microbial control by
4   helping to maintain a disinfectant residual and/or reducing biofilms and sediments that encourage
5   biological growth. Improved microbial control can result in fewer Total Coliform Rule (TCR)
6   violations, fewer violations of the Surface Water Treatment Rule (SWTR) requirement to
7   maintain a disinfectant residual, and less potential for microbiologically-induced corrosion.
8
9   *Improve Chlorine Residual Maintenance*
10
11   Long hydraulic residence times, microbial growth, and corrosion products will all deplete
12 the disinfectant residual. The BMPs seek to reduce these factors and will therefore result in
13 higher and more consistent residuals throughout the distribution system.
14
15 *Reduce Corrosion*
16
17   Corrosion can cause Lead and Copper Rule (LCR) compliance problems, aesthetic
18 problems, and may eventually lead to leaks that can be sources of contamination to the system.
19 Corrosion of cast iron pipes can provide a habitat for microorganisms and increase the likelihood
20 of TCR violations. Some BMPs, such as pipe replacement or lining, can reduce corrosion.
21
22 *Reduce Nitrification*
23
24   The occurrence of nitrification in chloraminated systems can be reduced through the use of
25 distribution system BMPs. Reducing water age and controlling microbial growth will help
26 reduce nitrification episodes. Reducing chlorine demand will slow the decay of chloramines and
27 provide less free ammonia for nitrification.
28
29 **3.2.2   Potential Operational and Simultaneous Compliance Issues Associated with**
30 **   Distribution System BMPs**
31
32   Challenges of implementing the BMPs depend largely on the specific BMP. Examples of
33 some of these challenges include:
34
35   • **Re-suspension of sediments**
36
37   • **Issues with disposal of disinfected water**
38
39   • **Lining materials leaching into the water**
40
41   • **Less storage available for emergencies**
42
43   • **Increased water loss**
44

1   *Flushing Can Stir Up Sediments*
2
3   Some BMPs such as increasing storage pumping rates, using blow-offs, or flushing of
4   pipes can cause re-suspension of sediments that had settled in the storage facilities or pipes.
5   Sediments can also accumulate in storage tanks, and increasing drawdowns can resuspend the
6   sediments. These sediments can cause temporary aesthetic complaints and may also contain
7   microbes or particulate metals such as lead, copper, and iron.
8
9   Recommendations for Addressing this Issue
10
11   A properly implemented flushing program can remove the sediments from the pipes and
12   can result in a positive long term impact. There are many references listed in the Section 7.5,
13   Distribution System Management, that can that can be used to plan, design, implement, and
14   monitor a good flushing program that removes sediment from the system and minimizes
15   aesthetic problems (AWWA 2002b, AWWA 2005b, Kirmeyer et al., 2000b).
16
17   *Issues with Disposal of Disinfected Water*
18
19   Utilities flushing their distribution systems should be aware of state or local regulations
20   on disposal of chlorinated or chloraminated water. If flushed water flows directly into natural
21   waters, systems should consider removing the disinfectant chemicals prior to discharge to protect
22   the aquatic environment.
23
24   Recommendations for Addressing this Issue
25
26   The AWWARF report, *Guidelines for the Disposal of Chlorinated Water* (Tikkanen, M.
27   et al. 2001) provides information on dechlorination techniques in use by water systems. Some
28   utilities use straightforward field methods such as a bag filled with a de-chlorinating agent placed
29   in the flowing water, while other systems have sophisticated metering and storage equipment
30   installed in trailers.
31
32   *Lining Materials Can Leach Into Water*
33
34   Some lining materials can leach chemicals into the water if not properly handled or
35   applied.
36
37   Recommendations for Addressing this Issue
38
39   It is important to make sure the lining material has been independently certified against
40   NSF/ANSI Standard 61. Manufacturers' instructions and appropriate standards should be
41   followed in lining the pipe and returning it to service as well. In addition to following the
42   certifying agency's and manufacturer's recommendations, many utilities will conduct their own
43   water quality tests for compounds of interest including VOCs and taste and odor causing

1 compounds before a new lining is returned or released to service.
2
3 *Less Storage Available for Emergencies*
4
5   Removing finished water storage facilities from service, while reducing DBPs and
6 improving microbial control, can result in less storage available for emergencies such as drought,
7 earthquakes, main breaks, firefighting, etc. To a lesser extent, some of the other finished water
8 storage BMPs can also reduce the amount of storage available for such events.
9
10   Recommendations for Addressing this Issue
11
12   Before changes are made to finished water storage, an analysis should be made of system
13 demand and pressure needs and fire flow requirements. This analysis should review appropriate
14 fire ordinances to determine the amount needed. In addition, emergency storage requirements
15 need to be addressed. Hydraulic models in combination with source planning can help determine
16 the amount of water to be maintained in storage in various parts of the system. Section 6.3
17 identifies several hydraulic models that may be helpful.
18
19 *Increased Water Loss*
20
21   Flushing programs will lead to a loss of water. This is an added expense and could be
22 troublesome in areas where sufficient water supply is a concern.
23
24   Recommendations for Addressing this Issue
25
26   The advantages of system flushing often outweigh the cost of lost water. Systems may,
27 however, want to minimize water loss through careful design of the flushing program.
28 Examining customer complaint and water quality records can help to focus flushing to the areas
29 and times where they are most needed.
30
31 **3.2.3   Recommendations for Gathering More Information**
32
33 *See Additional References*
34
35   Readers can turn to Section 7.1.5 in Chapter 7 for technical references associated with
36 implementing distribution system BMPs.
37
38 *Consider Additional Monitoring*
39
40   The following are some suggestions for additional monitoring that may benefit water
41 systems implementing distribution system BMPs:
42

✓ Routine chlorine residual and heterotrophic plate count (HPC-R2A) measurements in water leaving storage tanks and other distribution system locations with long residence times and in chloraminated systems. Online chlorine analyzers at storage facilities can be helpful as well.

✓ Increased total coliform, HPC, chlorine residual, and turbidity measurements in distribution system locations in areas being flushed.

✓ Periodic monitoring of pipe metals (e.g., iron if cast iron pipes are used, lead if lead solder is used) in distribution system regions where corrosion is suspected.

✓ Monitoring of pertinent chemicals and odor downstream of pipes that have been recently lined or replaced.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their operation or treatment practices. Examples of tools that can be used when distribution system best management practices are used for Stage 2 DBPR compliance include:

- Computer hydraulic and water modeling software, such as EPANET (U.S. EPA 2002b), that can be used to simulate hydraulic detention time and water quality in the distribution system

- The AWWA manual "Computer Modeling of Water Distribution Systems" (AWWA 2004a) that provides step-by-step instructions for the design and use of computer modeling for water distribution systems

- The "Stage 2 DBPR Initial Distribution System Evaluation Guidance Manual" (U.S. EPA 2006a) that provides distribution system water quality monitoring requirements for the Stage 2 DBPR and can be used to identify locations that tend to have high DBP levels

- The AwwaRF report, "Guidance Manual for Monitoring Distribution System Water Quality" (Kirmeyer 2002) which can be used to assist water utilities in implementing a distribution system water quality data collection and analysis program

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

1   **3.3   Moving the Point of Chlorination**
2
3   At conventional surface water treatment plants, chlorine can be added for prechlorination
4   at either the raw water intake or flash mixer, for intermediate chlorination ahead of the filters, for
5   postchlorination at the clearwell, or for rechlorination of the distribution system. While
6   inactivation of pathogenic organisms is its primary function, chlorine is used in drinking water
7   treatment for several other purposes, including:
8
9   • Control of nuisance Asiatic clams and zebra mussels
10   • Oxidation of iron and manganese
11   • Improved coagulation
12   • Taste and odor control
13   • Preventing algal growth in sedimentation basins and filters
14   • Removing color
15
16   Exhibit 3.1 summarizes the typical uses for each point of chlorine application
17
18
19   **Exhibit 3.1 Typical Chlorine Points of Application and Uses**
20

Point of Application	Typical Uses
Raw Water Intake	Zebra mussel and Asiatic clam control, control biological growth
Flash Mixer or Rapid Mix (prior to sedimentation)	Disinfection, iron and manganese oxidation, improved coagulation[1], taste and odor control, oxidation of hydrogen sulfide, algae control
Filter Influent	Disinfection, control biological growth in filter, iron and manganese oxidation, taste and odor control, color removal
Filter Clearwell	Disinfection, disinfectant residual
Distribution System	Maintain disinfectant residual

21   Source: *Alternative Disinfectants and Oxidants Guidance Manual*, USEPA 1999b.
22   [1]Not included as a typical use in the above reference, but documented by research
23
24
25   Public water systems with conventional treatment might consider moving the application
26   point for chlorine downstream within the plant to a point after DBP precursors have been
27   removed. Depending on the treatment plant, THM formation potential can be decreased by up to
28   50 percent as a result of precursor removal during coagulation and sedimentation (Singer and
29   Chang 1989).
30

1   **3.3.1   Advantages of Moving the Point of Chlorination**
2
3   By moving the point of chlorination downstream in the treatment process, a PWS can:
4
5   • **Reduce DBP concentrations in the finished water**
6
7   • **Reduce amount of disinfectant used**
8
9   • **Facilitate monthly TOC source water monitoring**
10
11   *Reduces DBPs*
12
13   Summers et al. (1996) presented the results from four studies evaluating the impact of
14   pretreatment on DBP formation. Jar tests were conducted to simulate water treatment through
15   rapid mix, coagulation, flocculation, and sedimentation. Chlorine was added at various points in
16   the jar testing to simulate the impact of various dose points on production of DBPs. The results
17   demonstrate the benefits of delaying the point of chlorination downstream in the treatment train
18   to take advantage of precursor removal during flocculation and sedimentation processes. Exhibit
19   3.2 summarizes the results from this study.
20
21
22   **Exhibit 3.2 Percent Reduction in DBP Formation by Moving Point of Chlorination**

Chlorination Point	TTHM Baseline (%)	TTHM Enhanced (%)	HAA5 Baseline (%)	HAA5 Enhanced (%)
Pre rapid mix	Baseline	17	Baseline	5
Post rapid mix	2	21	5	21
Mid flocculation	9	36	14	36
Post sedimentation	21	48	35	61

23   Notes: Source: USEPA 1997 based on Summers et al. 1996
24   Baseline = Baseline coagulant (alum) dose for optimal turbidity removal (30 mg/L)
25   Enhanced = Enhanced coagulant (alum) dose for optimal TOC removal (52 mg/L)
26
27
28   Exhibit 3.2 also includes a comparison of total trihalomethane (TTHM) and haloacetic
29   acid (five) (HAA5) concentrations when enhanced coagulation was used, and the benefits of
30   enhanced coagulation for reducing DBP production. The TTHM formation reduction of 21
31   percent by moving the chlorination point to post sedimentation is more than doubled to 48
32   percent by enhanced coagulation. The reduction in HAA5 formation increases from 45 to 61
33   percent under enhanced coagulation with post sedimentation chlorination. Therefore, DBP
34   control by selecting the optimal dose location and conditions, along with enhanced precursor
35   removal, can significantly reduce DBP formation. For a more detailed discussion of enhanced

1   coagulation and its simultaneous compliance issues, refer to Section 3.7 of this manual.
2
3   *Reduces Amount of Disinfectant Used*
4
5   If a system moves its point of chlorination downstream after a significant amount of
6   organic matter has been removed, the chlorine demand of the water will be lower. In some
7   cases, the system may be able to take advantage of the reduced chlorine demand to reduce the
8   overall chlorine dose needed to achieve the required CT. The system would benefit not only in
9   reduced chemical costs, but may also reduce operational costs if they decrease their number of
10 chlorine injection points.
11
12 *Facilitates Source Water TOC Monitoring*
13
14   The Stage 1 D/DBPR requires surface water systems (or systems using ground water
15 under the direct influence of surface water) using conventional filtration treatment to monitor
16 each treatment plant for TOC. Systems are required to collect TOC samples from the source and
17 the finished water. Source water TOC samples must be collected prior to any treatment,
18 including chlorination.
19
20   Some PWSs that are required to conduct TOC sampling prechlorinate at or near the
21 source water intake. These systems currently have to turn off their chlorination in order to
22 collect a proper source water TOC sample. Although it's a minor benefit of moving chlorination
23 downstream in the treatment process, those systems would no longer have to turn off their
24 chlorination in order to collect their source water TOC sample.
25
26 **3.3.2   Potential Operational and Simultaneous Compliance Issues Associated with Moving**
27   **the Point of Chlorination**
28
29   Many PWSs benefit from other functions of prechlorination in addition to its use as a
30 disinfectant. Chlorine can oxidize iron and manganese, improve coagulation, enhance color
31 removal, improve taste and odor, as well as control biological growth at different stages of
32 treatment. Because it has several other functions, some PWSs may find that there are drawbacks
33 to moving the point of chlorination further downstream in the treatment process. Moving the
34 point of chlorination further downstream in the treatment process can:
35
36   • **Reduce CT and thus decrease disinfection effectiveness**
37
38   • **Increase filter fouling**
39
40   • **Limit Asiatic clam or zebra mussel control**
41
42   • **Limit coagulation and filtration effectiveness**

1
2   • **Provide less effective treatment for iron and manganese**
3
4   • **Affect pH of water being treated, possibly requiring adjustment of water**
5   **treatment chemistry**
6
7   • **Require a higher disinfectant dosage to meet CT requirements downstream**
8
9   This section discusses these issues and provides some recommendations for addressing them.
10
11   *Reduces CT*
12
13   Disinfection effectiveness is measured in terms of CT (concentration $\times$ contact time). If a
14   PWS receives CT credit for contact time prior to filtration and then moves its point of
15   chlorination further downstream in the treatment process, which system may have to adjust its C
16   to accommodate reduced T.
17
18   Recommendations for Addressing this Issue
19
20   Systems should examine hydraulic conditions and maximize contact time where possible.
21   Clearwells can be modified (e.g., baffling and/or improved inlet and outlet structures added) to
22   improve their hydraulic performance. Constructing additional storage or dedicated disinfection
23   contact basins can also increase CT.
24
25   A water system should evaluate the CT that it can achieve downstream of the new
26   application point to ensure that sufficient CT can be maintained once the point of chlorination
27   has been moved. The evaluation should be done for the organism for which the disinfectant is
28   least effective. A system may also want to break up its CT segments into smaller segments. For
29   example, if the section from the raw water intake until the filters had been considered as a single
30   section for performing CT calculations and the point of chlorination is moved until after the
31   flocculation basin, a system can still receive some credit for section between the flocculation
32   basin and the filters. See the *Disinfection Profiling and Benchmarking Guidance Manual*
33   (USEPA 1999a) for more details on calculating CT and using segments. This evaluation should
34   review seasonal impacts on CT (e.g., cold water conditions when higher CT values are needed or
35   if the water's pH increases during algae blooms in the warmer water months).
36

Potential for Increased Filter Fouling

Prechlorination is often used to minimize operational problems associated with biological growth in water treatment plants. Prechlorination can prevent slime formation on filters, pipes, and tanks, and reduce potential taste and odor problems associated with such slimes. It can also prevent algal growth which can clog filters and cause turbidity problems. Many sedimentation and filtration facilities operate with a small chlorine residual to prevent growth of algae and bacteria in the launders and on the filter surfaces.

Recommendations for Addressing this Issue

If a system is concerned about the potential for algal growth and filter fouling after prechlorination is stopped, there are alternatives the system can consider. If chlorine is being added before the coagulation and flocculation steps, operators may want to consider moving the chlorination point so that it follows these steps but comes before filtration.   Adding chlorine immediately before the filters may be an effective way for the system to prevent filter fouling, yet not allow the chlorine to come into contact with the water when the water still contains unsettled DBP precursors (see case study No. 1 in Appendix B).

Systems may be able to eliminate the prechlorination step at certain times of the year, and return to prechlorination when microbial fouling is more likely to occur during the treatment process, such as when there is algal growth in the source water. They may also consider continuing to prechlorinate, but adjusting the prechlorination dose depending on source water conditions or water temperature.

> **Adding chlorine immediately before the filters may be an effective way for the system to prevent filter fouling from biological growth.**

Lastly, a system may consider using an alternative preoxidant, such as potassium permanganate or chlorine dioxide. These oxidants can provide benefits similar to chlorine in terms of iron, manganese, or algae control without forming significant amounts of TTHM or HAA5. They can also reduce chlorine demand before chlorination is applied. Readers should refer to the *Alternative Disinfectants and Oxidants Guidance Manual* (USEPA 1999b) for more information.

Asiatic Clam and Zebra Mussel Control

The Asiatic clam (*Corbicula fluminea*) was introduced to the United States from Southeast Asia in 1938 and now inhabits almost every river system south of 40° latitude (Britton and Morton 1982, Counts 1986). This mollusk has invaded many source waters, clogging source water transmission systems and valves, screens, and meters; damaging centrifugal pumps; and causing taste and odor problems.

1
2   The zebra mussel (*Dreissena polymorpha*) population in the United States has expanded
3   very rapidly. Zebra mussels have been found in the Great Lakes, Ohio River, Cumberland River,
4   Arkansas River, Tennessee River, and the Mississippi River south to New Orleans (Lange 1994).
5
6   Many PWSs add chlorine at their intakes to control Asiatic clam and zebra mussel
7   growth. For those systems with intakes a significant distance from their treatment plants,
8   prechlorinating for zebra mussel control may allow a substantial amount of time for TTHM or
9   HAA5 formation prior to any precursor removal process.
10
11   Recommendations for Addressing this Issue
12
13   Systems that add chlorine to control Asiatic clams and have problems with elevated
14 TTHM or HAA5 concentrations may want to consider using an alternative oxidant, such as
15 monochloramine or chlorine dioxide, to control clam growth in their systems. If
16 monochloramine is used, water systems using the monochloramine to also satisfy CT
17 requirements will need to perform a disinfection benchmark, bearing in mind that the CT
18 required for viral inactivation using chloramines is substantially greater than that for chlorine,
19 and should ensure that adequate disinfection is being provided after switching disinfectants.
20
21   Cameron et al. (1989) compared the
22 effectiveness of free chlorine, potassium
23 permanganate, monochloramine, and chlorine
24 dioxide for controlling the juvenile Asiatic clam.
25 Monochloramine was found to be the best for

> **Monochloramine was found to work well for controlling juvenile clams without forming DBPs.**

26 controlling juvenile clams without forming DBPs. Further research showed that the
27 effectiveness of monochloramine increased greatly as the temperature increased (Cameron et al.
28 1989). Belanger et al. (1991) showed that pre-formed monochloramine with excess ammonia
29 was more effective for controlling Asiatic clams than either total residual chlorine,
30 monochloramine, bromine, or copper. Chlorination at 0.25 to 0.40 mg/L total chlorine residual
31 at 20 to 25° C controlled clams of all sizes, but the same dosage had minimal effect at 12 to 15°
32 C.
33
34   Systems with elevated DBPs may also want to consider using an alternative zebra mussel
35 control strategy. Permanganate has been found to be effective for zebra mussel control and has
36 been used. Chlorine dioxide and ozone have shown promise as effective oxidants that can be
37 used for zebra mussel control. Antifouling coatings can work by slowly releasing into the water
38 a toxic substance, often an organo-metallic compound that prevents the zebra mussel larvae from
39 settling on the pipes. PWSs should check with their State if they are considering a chemical
40 control method, to make sure that the chemical is approved for use in a drinking water supply.
41

1   There are many other approaches to zebra mussel control being developed and tested.
2   These methods include:
3
4   • the use of electrical fields to kill veligers (zebra mussel larvae)
5   • ultrasonic treatment to prevent settlement
6   • oxygen deprivation
7   • sand infiltration beds
8   • thermal control (AWWA 2003c)
9
10   In addition, some polymers have been tested recently that show promise.
11
12   *Coagulation and Filtration Effectiveness*
13
14   Research has shown that using a preoxidant ahead of coagulation can have a positive
15   effect on coagulation and filtration with respect to particle removal (Becker et al. 2004). By
16   moving chlorination to a point after filtration, a water system may find that it needs to develop
17   new strategies for turbidity and particle control.
18
19   Recommendations for Addressing this Issue
20
21   Water systems moving chlorination to a point after filtration that can no longer achieve
22   low filter effluent turbidity values or particle counts may want to consider using a preoxidant
23   other than chlorine to improve filter performance. The strongest preoxidants have shown the
24   maximum benefit to filtration, so a system can achieve similar benefits by applying chlorine
25   dioxide or ozone. Systems that choose to do this should consult the Section 5.4 (chlorine
26   dioxide) or Section 5.2 (ozone) of this guidance manual to determine possible effects of these
27   steps.
28
29   *Iron and Manganese Control*
30
31   Although not harmful to human health at the low concentrations typically found in water,
32   iron and manganese can cause staining and taste problems. Iron and manganese compounds are
33   treated by oxidation to produce a precipitate that is subsequently removed by sedimentation and
34   filtration. Systems with high manganese levels should also be aware that a manganese coating
35   may have developed on their filters when pre-oxidation was practiced. This layer could dissolve
36   if pre-oxidation is no longer practiced and/or the pH drops (Angara et al 2004).
37
38   Recommendations for Addressing this Issue
39
40   Systems should be careful to consider how eliminating prechlorination may impact other
41   removal mechanisms during the treatment process. Some may be able to use and alternative
42   oxidant or reduce their prechlorination dose if the chlorine dose required for iron or manganese

1   removal is lower than what is currently being added. The oxidation of iron and manganese can
2   usually be accomplished while maintaining a minimum residual. Potassium permanganate is an
3   effective alternative oxidant to chlorine for iron and manganese oxidation and does not result in
4   TTHM or HAA5 formation. Various alternatives are discussed in greater detail in the
5   *Alternative Disinfectants and Oxidants Guidance Manual* (USEPA 1999b) and the *Guidance*
6   *Manual for Enhanced Coagulation and Precipitative Softening* (USEPA 1999h).
7
8   *Problems with a Change in pH*
9
10   Moving the point of chlorination or
11 eliminating prechlorination may result in a change in
12 water pH. Adding gaseous chlorine decreases
13 water's pH, whereas adding hypochlorite increases
14 water's pH.

> **Impacts of pH changes on compliance and operational issues associated with pH are described in Section 3.4.**

15
16   Recommendations for Addressing this Issue
17
18   Water systems that use a coagulant should consider whether the elimination of
19 prechlorination and the resulting change in pH would require the system to adjust its coagulant
20 dose or add other chemicals to control pH. Systems with corrosion control should also consider
21 whether a pH change due to the elimination of prechlorination would require the system to alter
22 its corrosion control chemical dose. Impacts of pH changes on compliance and operational
23 issues are described in Section 3.4.
24
25 *Problems with MRDL Compliance*
26
27   If prechlorination is reduced or eliminated and contact time is decreased, CT can be
28 increased by raising the residual concentration through the disinfection zone. If this approach is
29 taken, high disinfectant residuals may persist into the distribution system. A public water
30 system, however, must maintain disinfectant residual concentrations that meet the MRDL
31 requirements of the Stage 1 D/DBPR. The running annual average (RAA) of the free chlorine
32 residual measured in the distribution system must not exceed the 4.0 mg/L MRDL. Also, if the
33 chlorine residual in the delivered water is increased, the number of customers that will notice a
34 chlorinous odor may increase and generate more frequent customer complaints.
35
36 **3.3.3   Recommendations for Gathering More Information**
37
38 *Read the Case Study*
39
40   For more information on simultaneous compliance issues associated with moving the
41 point of chlorination and how to address them, see ***Case Study #1 - Moving the Point of***
42 ***Chlorination*** starting on page B-3 of Appendix B. This case study describes how two small
43 PWSs with high THM concentrations were able to comply with the requirements of the Stage 1

1   D/DBPR and Stage 2 DBPR by adjusting their coagulation methods and changing the point of
2   chlorination, while also optimizing distribution operations to minimize water age and optimizing
3   booster chlorine use. Their greatest operation issue was a need for increased attention to solids
4   removal as a result of enhanced coagulation.
5
6   *See Additional References*
7
8   Readers can turn to Sections 7.1.1, 7.1.2, and 7.1.6 in Chapter 7 for technical references
9   associated with moving the point of chlorination.
10
11 *Consider Additional Monitoring*
12
13   The following are some suggestions for additional monitoring that may benefit water
14 systems moving their point of chlorination:
15
16   ✓ Water systems that reduce or eliminate prechlorination should carefully review pH
17   data to ensure that treatment processes and materials will not be adversely affected.
18
19   ✓ Systems with the potential for iron or manganese problems that move, reduce, or
20   eliminate prechlorination should consider monitoring for those metals at the entry
21   point to the distribution system. Those systems with clearwells and long residence
22   times may want to check whether iron or manganese solids are accumulating in the
23   clearwell.
24
25   ✓ Customer complaint monitoring can be traced along with color and taste and odor
26   evaluations to make sure aesthetic quality has not been lost.
27
28   ✓ The impact of algal blooms on sedimentation and filter performance can be tracked
29   by measuring turbidity and/or particle counts before and after filtration.
30
31 *Consider Other Tools*
32
33   In addition to water quality monitoring, there are additional tools available in Chapter 6
34 to help systems evaluate and improve their current water system in relation to the compliance
35 issues they may face when modifying their operation or treatment practices. Examples of tools
36 that can be used when moving the point of chlorination is used as a Stage 2 DBPR compliance
37 technique include:
38
39   • The AwwaRF report "Internal Corrosion of Water Distribution Systems" (AWWARF
40   and DVGW-Technologiezentrum Wasser 1996) which provides bench-scale and pilot
41   testing protocols that can be used to evaluate the impacts of pH changes on corrosion
42   potential. Such pH changes may occur if a utility switches disinfectants
43

1   • The paper "Predicting the Formation of DBPs by the Simulated Distribution System"
2   published by Koch et al. (1991) can be used to predict the amounts of DBPs that
3   would form in a distribution system. Key parameters (including chlorine dosage,
4   incubation temperature, and incubation holding time) are chosen to simulate the
5   conditions of the treatment plant and the distribution
6
7   • The second version of "Water Treatment Plant Model" (U.S. EPA. 2001h.) developed
8   by USEPA that assists utilities with implementing various treatment changes while
9   maintaining adequate disinfection and meeting the requirements of the Stage 2
10   DBPR.
11
12 Readers are encouraged to read through Chapter 6 before making any final compliance decisions.
13
14
15 **3.4   Decreasing pH**
16
17   Pathogen inactivation by chlorine is affected by
18 pH. This is because the germicidal efficiency of
19 hypochlorous acid (HOCl) is much higher than that of

> **Pathogen inactivation by chlorine depends on pH.**

20 hypochlorite ion (OCl $^-$), and the distribution of chlorine species between HOCl and OCl$^-$ is
21 determined by pH. Because HOCl dominates at low pH values (< 7.5), chlorination provides
22 more effective disinfection at low pH. At high pH values (> 8.0), OCl $^-$ dominates, which
23 causes a decrease in disinfection efficiency.
24
25   Public water systems can reduce their pH to increase disinfectant efficiency, enabling
26 them to lower their disinfectant dose and still achieve the same amount of disinfection, thereby
27 potentially limiting DBP formation. The system may want to raise the pH again before it enters
28 the distribution system to avoid corrosion problems within the distribution system.
29
30   pH can also impact the reactions between chlorine and NOM, resulting in conditions that
31 favor either TTHMs or HAA5 formation. At higher pH, more THMs tend to be formed. Lower
32 pH tends to favor HAA formation. This information can be used by systems to influence TTHM
33 or HAA5 formation at the plant or in the distribution system by controlling the pH. Systems that
34 have high TTHM levels but relatively low HAA5 may be able to reduce TTHM formation by
35 lowering pH. However, these systems will need to pay special attention to corrosion issues.
36
37 **3.4.1 Advantages of Decreasing pH**
38
39   Advantages to decreasing pH include:
40
41   • **The same CT can be achieved with a lower disinfectant dose**
42

1   • **Can reduce formation of some DBPs**
2
3   *Same CT Can Be Achieved with Lower Disinfectant Dose*
4
5   Virus inactivation studies have shown that 50 percent more contact time is required at pH
6   7.0 than at pH 6.0 to achieve comparable levels of chlorine inactivation. These studies also
7   demonstrated that an increase in pH from 7.0 to 8.8 or 9.0 requires six times the contact time to
8   achieve the same level of virus inactivation (Culp and Culp 1974).
9
10   Exhibit 3.3 uses the required CT values in the National Primary Drinking Water
11   Regulations to show how a PWS complying with the CT requirements for water at a higher pH
12   value could reduce its pH and decrease its free chlorine residual. For example, at 10°C, pH 7.0
13   and 1.0 mg/L free chlorine, a water system would need a minimum CT of 112 to achieve 99.9
14   percent inactivation of *Giardia lamblia* cysts. If the water temperature were to stay the same but
15   the water's pH were reduced to 6.5, a minimum CT of 94 would be needed to achieve 99.9
16   percent *Giardia* inactivation. Exhibit 3.3 shows that a water system that had been in compliance
17   with CT requirements for pH 7.0 could reduce its free chlorine residual from 1.0 to 0.6 mg/L and
18   still have enough CT to satisfy the CT requirement if they reduced their pH to 6.5.
19
20

1 **Exhibit 3.3 Impact of pH on *Giardia lamblia* CT$_{99.9}$ at 10˚C Using Free Chlorine**
2

The chart shows, with axes "Free Chlorine *Giardia lamblia* CT at 10 degrees C" (y-axis, 50 to 200) versus "pH" (x-axis, 6 to 9.5):

Legend:
- ▲ 0.6 mg/L
- ■ 1.0 mg/L

- *pH=7.0, free Cl$_2$ = 1.0 mg/L, CT = 112 mg-min/L*
- *pH=7.0, free Cl$_2$ = 0.6 mg/L, CT = 107 mg-min/L*
- *pH=6.5, Cl$_2$ = 1.0 mg/L, CT required is 94 mg-min/L*

A water system satisfying CT requirements for 1.0 mg/L free Cl$_2$ at pH 7.0 would have enough CT to satisfy CT requirements for 0.6 mg/L free Cl$_2$ at pH 6.5.

3
4
5   Adapted from CT tables in 40 CFR 141.74 National Primary Drinking Water Regulations
6
7
8   *Can Reduce DBP Formation*
9
10   The pH of water can impact the formation of halogenated byproducts (Reckhow and
11 Singer 1985, Stevens et al. 1989). Exhibit 3.4 compares formation of byproducts at three pH
12 levels (adapted from Stevens et al., 1989). Note that TTHM show generally lower formation at
13 the lowest pH level. The formation of HAAs, however, generally increases at lower pH levels.
14

Exhibit 3.4 Impacts of pH on Formation of DBPs

Byproduct	Conditions of Formation		
	Chlorination at pH 5.0	Chlorination at pH 7.0	Chlorination at pH 9.4
TTHM	Lower Formation	Basis for Comparison	Higher Formation
Trichloroacetic Acid (one of the HAA5)	Similar Formation	Similar Formation	Lower Formation
Dichloroacetic Acid (one of the HAA5)	Similar Formation - perhaps slightly higher at pH 7		

Source: adapted from Stevens et al. 1989

Other studies show that limiting pH levels in the distribution system to less than 8.2 may help to limit TTHM formation (Edwards and Reiber 1997). Four LCR compliance strategy case studies showed that TTHM increases were less than 20 percent if the pH shift implemented for lead and/or copper corrosion control was near neutral (7.0) to less than 8.2. When the pH was shifted from near neutral to greater than 8.5, TTHM production increased as much as 40 percent. At one plant, TTHM increases due to pH adjustment ranged from 2 percent at a pH of 8.1 to 43 percent at a pH of 8.7. HAA production was shown to decrease about 10 percent for all of the pH increases implemented (Edwards and Reiber 1997).

3.4.2   Potential Operational and Simultaneous Compliance Issues Associated with Decreasing pH

Potential issues associated with reducing pH to enhance chlorine disinfection include:

- **May increase HAA5 formation**

- **Can adversely affect treatment plant structures and coatings (i.e., corrosion of pipes, tanks, etc.)**

- **Can affect treatment chemistry, sludge dewatering, and inorganic solubility**

- **Can cause problems with corrosion control and LCR compliance**

- **If chlorine dose is reduced during primary disinfection, it may be difficult to maintain secondary disinfection levels throughout the distribution system.**

1   *HAA5 May Increase*
2
3   Lower pH conditions may result in higher HAA5 concentrations. Reckhow and Singer
4   (1985) studied humic acid chlorination in laboratory tests and found that trichloracetic acid
5   concentrations reached a maximum when the water was in the acidic pH range. When pH levels
6   were increased, trichloroacetic acid concentrations decreased and chloroform (a key component
7   of TTHM) concentrations increased. Other studies, such as Stevens et al. (1989), have not found
8   comparable increases in HAA5 concentrations when pH levels decreased from neutral to slightly
9   acidic.
10
11   Recommendations for Addressing this Issue
12
13   In general, pH values in distribution systems are unlikely to fall in the acidic range given
14 the requirements of the Lead and Copper Rule and good corrosion control practices. Systems
15 can conduct simulated distribution system (SDS) studies to simultaneously evaluate impacts of
16 pH adjustment on both TTHM and HAA5 formation. The results of these bench-scale tests can
17 help identify the optimal pH for balancing the need to control both TTHM and HAA5.
18
19   Systems can also evaluate pH fluctuation trends throughout their distribution systems.
20 For poorly buffered waters, the pH can tend to drift upward as the water reacts with cement-lined
21 pipes. Increases in pH throughout the distribution system would tend to favor TTHM formation
22 and reduce HAA5 formation.
23
24 *Adverse Effects on Treatment Plant Materials*
25
26   If pH levels are lowered to enhance disinfection, components of the treatment plant may
27 be adversely affected by the acidic conditions. Metal components of the plant may corrode;
28 plastic or rubber components may deteriorate more quickly; cement/concrete leaching and
29 deterioration may be exacerbated.
30
31   Recommendations for Addressing this Issue
32
33   Systems should evaluate the effects of decreased pH on treatment plant components, such
34 as pipes and linings. Based on their evaluation, systems should adjust the:
35
36   •   maintenance schedules,
37   •   materials, or
38   •   point of pH adjustment
39
40 so that the chances of leaks, leaching, or equipment failure are minimized.
41

1   *Adverse Effects on Treatment Chemistry, Inorganics Solubility, Settling, and Sludge Dewatering*
2
3   Reducing the water pH can cause problems with increased solubility of inorganics, and
4   may result in increased iron and manganese levels. Lower treated water pH can also result in
5   recalcification of lime-softened waters, resulting in increased turbidity. Variation of pH levels
6   can affect treatment chemistry and impact settling and sludge dewatering. System operators
7   should carefully consider the impacts of pH adjustment before implementing such a significant
8   change to their treatment process.
9
10   Manganese is typically removed from water using direct oxidation/coagulation/filtration
11   or filter adsorption/oxidation (i.e., green sand). Chlorine is sometimes used for the oxidation
12   step of this process. A low pH hinders the direct oxidation process because the rate of
13   manganese oxidation increases as pH increases. Therefore, systems using chlorine or potassium
14   permanganate for manganese oxidation should be aware that, if the pH is reduced before
15   manganese oxidation, more time may be needed for the manganese to be removed.
16
17   The minimum solubility of aluminum occurs at a pH of 6.2 to 6.5. Those water systems
18   that use alum as a coagulant and operate at a pH of less than 6.0 that do not increase their pH
19   before filtration may be impacted by the solubility of aluminum at this low pH. If the pH is not
20   adjusted before filtration, aluminum carryover problems may result.
21
22   <u>Recommendations for Addressing this Issue</u>
23
24   Systems with high manganese levels that lower the pH prior to filtration may want to
25   consider using an oxidant that is less pH dependent to oxidize manganese, such as ozone.
26   Alternatively, a system could choose to lower the pH after oxidation and filtration.
27
28   Systems using alum as a coagulant can adjust pH to greater than 6.5 before the filters to
29   avoid aluminum passing into the distribution system.
30
31   *Corrosion Control and LCR Problems*
32
33   A lower pH in the distribution system can increase corrosion of cement linings and iron
34   pipe. It can also favor corrosion of lead and copper plumbing, causing LCR compliance
36   problems. Corrosion of unlined cast iron water mains
38   can favor microbial regrowth, which can affect TCR
40   compliance.
42

A pH change can disrupt distribution system surfaces causing aesthetic problems or the release of inorganic contaminants and microbes.

44   Any changes in the pH levels historically
46   maintained in a distribution system can disrupt films
48   and scales that have accumulated on natural corrosion
49   surfaces. These films and scales have formed over long periods of time and may be helping to
50   passivate the corrosion process from further development. A pH change can disrupt these

1 surfaces, releasing inorganic contaminants as well as microbes and organic carbon trapped in the
2 films and scales. Although the disruption of films or scales in the distribution system may not
3 result in a direct violation of either the DBP or microbial rules, the disruption could cause
4 aesthetic problems or the release of microbes. Disruption of scale can also cause maintenance
5 problems in utility facilities such as tanks, valves and pumps, as well as in customer sprinkler
6 systems and commercial facilities.
7
8   Recommendations for Addressing this Issue
9
10   If pH is lowered during disinfection, systems should consider adjusting pH upward and
11 possibly adjusting alkalinity before the water enters the distribution system to reduce corrosion
12 of pipe materials. If finished water pH is reduced, the system should consider other corrosion
13 control strategies.
14

16   Systems can control corrosion by optimizing pH,
18 alkalinity, and dissolved inorganic carbon (DIC).

Water systems should carefully research the implications of using a corrosion inhibitor before adding it as a treatment step.

20 Another alternative is to add a corrosion inhibitor that is
22 phosphate- or silica-based to form a protective coating
24 on pipes. Some utilities, however, have elected *not* to
26 use phosphate-based corrosion inhibitors because the
27 publicly owned treatment works (POTW) receiving the wastewater has phosphorus limits in their
28 NPDES and sludge disposal permits.
29
31   Regardless of the type of corrosion treatment
33 used, it should be tested before it is introduced, if
35 possible. Pilot testing is discussed in more detail in

Appendix D provides additional guidelines for systems evaluating their corrosion control options and information on proper piloting procedures.

37 Section 6.5 of this manual. Large systems should
39 have completed corrosion control studies, as required
41 by the LCR. Smaller water systems may have
43 conducted studies if required by the state. Any
44 system that subsequently changes their treatment must notify the state and may be required to
45 conduct a new corrosion control study. In any event, LCR corrosion control studies should be
46 used as a starting point to assess the impacts of changes in distribution system water quality on
47 corrosion and LCR compliance and determine the best corrosion control treatment strategy.
48 Appendix D provides additional guidelines for systems evaluating their corrosion control options
49 and information on proper testing procedures.
50
51 *Reduced Disinfectant Residual Concentration*
52
53   Systems that are considering lowering their disinfectant dose to take advantage of
54 additional CT credit at a lower pH should consider impacts on maintaining the desired
55 disinfectant residual level throughout the distribution system. A lower disinfectant dose may
56 mean a lower disinfectant residual concentration leaving the treatment plant if the system does

1   not have a chlorine dose point after the clearwells.
2
3   Recommendations for Addressing this Issue
4
5   Additional chlorine will be needed prior to entry to the distribution system, or through
6   booster disinfection, to account for the decrease in chlorine during primary disinfection.
7
8   **3.4.3   Recommendations for Gathering More Information**
9
10 *Read the Case Study*
11
12   For more information on simultaneous compliance issues associated with modifying pH,
13 see ***Case Study #2 Modifying pH During Chlorination*** starting on page B-13 of Appendix B.
14 This case study describes how one PWS used pH depression via carbon dioxide injection ahead
15 of the flocculation basins to reduce DBPs and DBP precursors. The system was also able to
16 increase coagulation efficiency, increase CT throughout the treatment plant (allowing for
17 reduced chlorine injection), and increase and stabilize pH levels in the distribution system by
18 increasing the buffering capacity following caustic soda addition. Their greatest operation issue
19 was a need for a pressurized solution feed to solubilize CO_2.
20
21 *See Additional References*
22
23   Sections 7.1.2 and 7.1.3 in Chapter 7 contain technical references associated with DBP
24 formation and corrosion, including references on how each process is affected by pH. General
25 water treatment references in Section 7.1.1 can also provide useful information.
26
27 *Consider Additional Monitoring*
28
29   The following are some suggestions for additional monitoring that may benefit water
30 systems that are reducing their pH during chlorination:
31
32   ✓ If alum is used as a coagulant and pH is not adjusted back up before filtration,
33   systems should test periodically for aluminum in the finished water.
34
35   ✓ Systems should perform routine pH and alkalinity monitoring at significant locations
36   throughout the treatment plant, especially after corrosion control chemicals have been
37   added.
38
39   ✓ Where it may be a problem, systems should perform periodic monitoring of iron and
40   manganese in the finished water.
41

✓ Systems can perform additional HPC and total coliform monitoring in the distribution system near locations where there is reason to believe that scale may have been dislodged.

✓ Systems can track customer complaints, color, and turbidity in the distribution system if there is reason to believe that changes in pH can affect scales and films.

The purpose of these monitoring suggestions is specifically to address and prevent potential simultaneous compliance issues.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their operation or treatment practices. Examples of tools that can be used when modifying pH during chlorination is used for Stage 2 DBPR compliance include:

- The SDS and material-specific (MS-SDS) procedures described by Koch et al (1991) and Brereton and Mavinic (2002), respectively, which describe bench-scale and pilot-scale tests that can be used to evaluate DBP formation under varying chlorine, temperature, pH conditions

- The AwwaRF report "Internal Corrosion of Water Distribution System" (AWWARF and DVGW-Technologiezentrum Wasser 1996) which provides bench-scale and pilot testing protocols that can be used to evaluate changes in corrosion potential due to pH changes;

- The AwwaRF report "Optimizing Corrosion Control in Water Distribution System" which provides techniques for instantaneous corrosion monitoring

- The "Guidance Manual for Monitoring Distribution System Water Quality" (Kirmeyer, 2002) which can be used to assist water utilities in implementing a distribution system water quality data collection and analysis program

- The second version of "Water Treatment Plant Model" (U.S. EPA 2001h) developed by USEPA that assists utilities to implement various treatment changes while maintaining adequate disinfection and meeting the requirements of Stage 2 DBPR.

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

1   **3.5   Reducing Chlorine Dose under Warm Water Conditions**
2
3   In general, as temperature increases, chlorine reaction kinetics increase. The increased
4   kinetics mean that disinfection effectiveness will improve, but it also means rates of DBP
5   formation reactions will increase. This section discusses the advantages and disadvantages of
6   adjusting chlorine dose based on the temperature of the source water.
7
8   **3.5.1   Advantages of Reducing Chlorine Dose under Warm Water Conditions**
9
10   The main advantage to reducing the chlorine dose under warm temperature conditions is
11   that fewer DBPs are likely to form when a lower chlorine dose is used. This is especially
12   pertinent because
13
14   • **Chlorine doses can be reduced when the water is warmer and still provide**
15   **comparable pathogen protection**
16
17   • **TTHM and HAA5 formation tends to be higher when water temperature**
18   **increases**
19
20   *Comparable Disinfection Protection with Less Chlorine*
21
22   Since chlorine effectiveness increases at higher temperatures, systems may want to
23   consider reducing their disinfectant dose in warm weather to reduce the formation of DBPs.
24   Disinfectant dose may not be lowered below the point of compliance with the CT requirements
25   dictated by the SWTR (USEPA 1989).
26
27   Exhibit 3.5 shows how water temperature affects the amount of CT needed to achieve 3-
28   log *Giardia lamblia* inactivation using chlorine to disinfect water with a pH of 7.0. Note, for
29   example, how the CT required at 5.0° C and a free chlorine dose of 1.0 mg/L is 149 mg-min/L.
30   But when the water temperature increases to 20° C and a free chlorine dose of 1.0 mg/L is used,
31   the CT required for 3-log *Giardia lamblia* inactivation decreases to 56 mg-min/L. Many water
32   systems are able to provide sufficient CT in the summer months and still use a lower
33   concentration of free chlorine than the concentration they are using during the winter to provide
34   the same pathogen protection.
35
36   Systems should proceed carefully if they choose this option to make sure that they
37   continue to meet CT requirements and do not diminish microbial quality in the distribution
38   system.
39
40

Exhibit 3.5 CT values (CT$_{99.9}$) for 99.9 percent inactivation of *Giardia lamblia* cysts by free chlorine at pH 7.0

Free chlorine residual (mg/L)	0.5° C	5.0° C	10.0° C	15.0° C	20° C	25° C
0.4	195	139	104	70	52	35
0.6	200	143	107	72	54	36
0.8	205	146	110	73	55	37
1.0	210	149	112	75	56	37

Adapted from 40 CFR Part 141 National Primary Drinking Water Regulations § 141.74

Less Chlorine When Rate of TTHM and HAA5 Formation Increases

By reducing the chlorine dose when water temperatures increase, a system may be able to reduce the formation of TTHM and HAA5. Krasner et al. (1990) found that the median TTHM concentrations in 35 systems were highest for those systems with the highest water temperature.

3.5.2   Potential Operational and Simultaneous Compliance Issues Associated with Reducing Chlorine Dose under Warm Water Conditions

Some potential issues associated with reducing the chlorine dose under warm temperature conditions are:

- **There may be seasonal variations in pathogen concentrations in the source water (e.g., water is used for recreational purposes, flowing waters with permitted wastewater discharges when flows are low)**

- **Some systems may need to maintain a higher disinfectant residual in the summer months to comply with the TCR**

- **Systems may encounter higher disinfectant demand in warm months, requiring higher disinfectant doses in order to meet chlorine demand and provide a stable finished water**

- **A reduction in chlorine dose may change the oxidation reduction potential of water in the distribution system**

Seasonal Variability of Pathogen Concentrations in the Source Water

Pathogen concentrations may increase in some surface water sources during the summer months. Concentrations of viruses and enteric bacteria are of particular concern, especially if the

1 source water is also used for recreational activity. Other pathogens such as *Cryptosporidium*
2 have been found to peak during spring runoff.
3
4   Recommendations for Addressing this Issue
5
6   Systems should evaluate uses of their source water and examine historical data to
7 determine if there is a trend in pathogen occurrence in the warmer months. Systems should also
8 consider consulting with their states to determine if others have collected data for the same
9 source. If data are not available, systems may want to collect surveillance fecal coliform or *E.*
10 *coli* samples at their intake to track whether they should be concerned about increased microbial
11 risk.
12
13 *Need to Maintain a Higher Residual in Warm Water Months to Comply with the TCR*
14
15   Increased water temperatures and corresponding increases in organic matter can enhance
16 coliform re-growth in the distribution system (LeChevallier et al. 1996). At the same time,
17 increased water temperatures result in faster chlorine residual decay in the distribution system,
18 which may allow for an increase in biofilm growth.
19
20   Recommendations for Addressing this Issue
21
22   If a PWS is considering reducing its chlorine dose, operators should understand how such
23 a decrease may affect the chlorine residual concentrations in the distribution system. Although
24 lower chlorine concentrations may reduce TTHM and HAA5 formation in the distribution
25 system, systems should carefully monitor the impacts of a low residual on microbial growth and
26 total coliform occurrence. Unidirectional flushing may also be a practical, cost-effective way to
27 reduce microbiological problems in the distribution system.
28
29 *Higher Disinfectant Demand in Warm Water Months*
30
31   Organic concentrations in raw water may increase in warm weather due to algae blooms,
32 aquatic plant growth, and other sources, creating an increase in chlorine demand. In addition,
33 since chlorine reaction rates increase as water temperature increases, chlorine demand and decay
34 will increase.
35
36   Recommendations for Addressing this Issue
37
38   Systems may need to add higher levels of chlorine to meet the chlorine demand prior to
39 distribution to maintain an adequate residual. Increases in taste and odor compounds from algal
40 blooms and other biotic activity may also motivate systems to maintain higher chlorine levels in
41 the summer months.
42

1   Some systems may want to consider the possibility of maintaining a lower chlorine
2 residual and boosting chlorination at points throughout the distribution system, rather than
3 adding a high dose at the entry point to try to maintain a residual throughout the distribution
4 system. See Section 3.2 for other BMPs that can be used to improve water age and maintain
5 more consistent disinfectant residuals.
6
7 *Change in Oxidation Reduction Potential*
8
9   Systems reducing their chlorine dose may see a change in the oxidation reduction (redox)
10 potential of their distribution system water. Since less oxidant will be added to the water, water
11 conditions may be more reduced. As a result, systems may see consequent electrochemical
12 reduction and dissolution of lead oxide in the distribution system, which could result in higher
13 lead concentrations at consumers' taps. Manganese deposits in the distribution system could also
14 increase causing taste, odor, and color complaints.
15
16   Recommendations for Addressing this Issue
17
18   Operators should measure the redox potential in their distribution system water before
19 and after the chlorine dose has been decreased. If a measurable change is noted, systems should
20 watch their lead concentrations closely to see if there is an increase that might be due to the more
21 reduced conditions. Systems with manganese in their water should track customer complaints
22 closely to see if manganese deposits have become more of an issue. If these issues arise, the
23 system should consider pre-treating the water with another oxidant, such as potassium
24 permanganate.
25
26 **3.5.3   Recommendations for Gathering More Information**
27
28 *See Additional References*
29
30   Readers can turn to Sections 7.1.1 and 7.1.4 in Chapter 7 for general references
31 associated with disinfection and technical references related to distribution system management.
32
33 *Consider Additional Monitoring*
34
35   The following are some suggestions for additional monitoring that may benefit water
36 systems that are reducing their chlorine dose:
37
38   ✓ Routine raw and finished water monitoring for *E. coli* and total coliform, especially
39   during the periods when the system is reducing its chlorine dose.
40
41   ✓ Increased chlorine residual measurements throughout the distribution system.
42
43   ✓ Increased HPC and total coliform surveillance monitoring in the distribution system.

1
2   ✓ Chlorine demand monitoring prior to chlorine addition for secondary disinfection to
3   make sure stable water is sent into the distribution system.
4
5   ✓ Inspection of distribution system pipe scales (including service lines and domestic
6   plumbing) to see if reductions in disinfectant residual and/or lower redox potential
7   may cause a problematic change in scale integrity and metal release.
8
9   The purpose of these monitoring suggestions is specifically to address and prevent potential
10 simultaneous compliance issues.
11
12 *Consider Other Tools*
13
14   In addition to water quality monitoring, there are additional tools available in Chapter 6
15 to help systems evaluate and improve their current water system in relation to the compliance
16 issues they may face when modifying their operation or treatment practices. Examples of tools
17 that can be used when varying the chlorine dosage is used for Stage 2 DBPR compliance include:
18
19   • The *Guidance Manual for Monitoring Distribution System Water Quality* (Kirmeyer
20   2002) which can be used to assist water utilities in implementing a distribution
21   system water quality data collection and analysis program
22
23   • The Standard Method 2350 (Oxidant Demand/Requirement) (APHA 1998) that
24   provides step-by-step instructions for the determination of chlorine demand during
25   various water quality conditions
26
27   • The paper "Predicting the Formation of DBPs by the Simulated Distribution System"
28   published by Koch et al. (1991) that can be used to closely monitor and predict
29   changes in DBP formation in the distribution system due to frequent chlorine dose
30   changes
31
32 Readers are encouraged to read through Chapter 6 before making any final compliance decisions.
33
34
35 **3.6   Modifying Presedimentation Basin Operations**
36
37   Presedimentation basins are basins placed before the rapid mix chamber and the
38 flocculation basins. Their purpose is to allow large particles and debris to settle out before the
39 main coagulation process and before any disinfectant is added. Presedimentation basins provide
40 a buffer to turbidity fluctuations and can lower DBP precursors entering the plant. Existing
41 basins can be modified to increase *Cryptosporidium* removal by adding a coagulant or increasing
42 residence time.

3.6.1 Advantages of Modifying Presedimentation Basin Operations

The advantages of presedimentation basins include:

- **Can lower DBP precursors prior to the addition of disinfectants**

- **Can possibly achieve 0.5 logs of *Cryptosporidium* removal credit under the LT2ESWTR**

Lower DBP Precursor Concentrations

By modifying presedimentation basins, systems can remove additional DBP precursors and decrease TTHM and HAA5 formation. Presedimentation basins are especially useful to systems with high levels of solids in their raw water or highly fluctuating turbidity. Addition of a coagulant in the presedimentation basin may increase the removal of DBP precursors.

> Addition of a coagulant in the presedimentation basin may increase the removal of DBP precursors.

Cryptosporidium Removal Credit

Systems with presedimentation basins can receive 0.5-log removal credit for *Cryptosporidium*. In order to get the credit for the presedimentation basin, all of the plant's water must pass through the basin and a coagulant must be added whenever the basin is operating. Alternatively, systems can conduct their LT2ESWTR monitoring for *Cryptosporidium* after the presedimentation basin to determine their treatment bin. If a system monitors for bin selection after the presedimentation basin, it cannot get the 0.5 log *Cryptosporidium* removal credit for the basin. These systems may, however, end up in a lower treatment bin due to *Cryptosporidium* removal in the presedimentation basin. See the *LT2ESWTR Toolbox Guidance Manual* (U.S. EPA 2003a) for additional information on receiving the removal credit.

3.6.2 Potential Operational and Simultaneous Compliance Issues Associated with Modifying Presedimentation Basin Operations

Potential issues associated with using presedimentation basins include:

- **Algal growth in presedimentation basins can increase DBP precursors**

- **Removal of settled solids can be difficult**

1 *Algal Growth*
2
3   Algae can grow in uncovered presedimentation basins that are not treated with a
4 disinfectant. The algae can add NOM to the water, increasing the chlorine demand, and can
5 negate DBP precursor removal obtained during presedimentation. Algae are also known to
6 produce taste and odor compounds and interfere with flocculation/sedimentation and filtration.
7
8   <u>Recommendations for Addressing this Issue</u>
9
10   There are several ways to prevent algae growth in presedimentation basins. Potassium
11 permanganate addition has been used with mixed success in efforts to stop algae growth and
12 control resulting tastes and odors. Covering basins to block ultraviolet (UV) light will also
13 prevent algae growth. Although this can be a more expensive solution, floating covers are
14 available that can provide a lower-cost alternative.
15
16 *Removal of Settled Solids*
18

20   Solids that accumulate in the bottom of
22 presedimentation basins should be removed
24 periodically. This is especially true when a
26 coagulant is added. If a coagulant is not added,
28 systems may be able to manage solids with periodic

> **Solids should be removed on a regular basis to prevent interference with plant performance and compliance with regulatory requirements.**

29 manual removal. Systems may not be able to use a coagulant if they cannot add solids removal
30 equipment to the basin. Although it presents additional costs to the plant, solids removal should
31 not interfere with plant production if it is done on a regular basis.
32
33   <u>Recommendations for Addressing this Issue</u>
34
35   If a coagulant is not used, systems should consider using two basins, taking one off-line
36 while the other is being cleaned to avoid stirring up sediment and allowing it to enter the plant.
37 Solids should be removed on a regular basis to prevent interference with plant performance and
38 compliance with regulatory requirements. Solids can be removed in various ways such as using
39 a sloped floor and center drain or specially designed vacuums or pumps. Removal can be
40 accomplished manually by regular cleaning or dredging.
41
42 **3.6.3   Recommendations for Gathering More Information**
43
44 *Read the Case Study*
45
46   For more information on simultaneous compliance issues associated with
47 presedimentation basins and how to address them, see ***Case Study #3 Presedimentation*** starting
48 on page B-21 of Appendix B. This case study describes how one PWS used was able to monitor
49 effluent from their presedimentation basins to determine their *Cryptosporidium* bin classification

1   for the LT2ESWTR. Operational issues include problems with algae blooms, which the system
2   was typically able to control by adding potassium permanganate to the basins.
3
4   *See Additional References*
5
6   Readers can turn to Section 7.1.1 in Chapter 7 for general technical references associated
7   with water treatment. The *Draft LT2ESWTR Toolbox Guidance Manual* (USEPA 2003a)
8   provides additional information on presedimentation.
9
10   *Consider Additional Monitoring*
11
12   The following are suggestions for additional monitoring that may benefit water systems using
13   presedimentation:
14
15   ✓ Turbidity measurements as water leaves the presedimentation basin and enters the
16   treatment plant, in order to detect impacts of sediment buildup or short-circuiting on
17   water quality entering the plant.
18
19   ✓ If algae growth is a problem, routine algal counts, chlorophyll *a* measurements, or Secchi
20   disk depth readings as feasible, to guide algae management efforts.
21
22   The purpose of these monitoring suggestions is specifically to address and prevent potential
23   simultaneous compliance issues.
24
25
26   **3.7   Enhanced Coagulation**
27
28   One way to remove NOM is to practice enhanced coagulation. Enhanced coagulation has
29   been shown to be an effective strategy for reduction of DBP precursors for many systems
30   (Krasner and Amy 1995). Enhanced coagulation can be accomplished by one or more of the
31   following operational changes:
32
33   • Increasing coagulant dose
34
35   • Changing coagulant
36
37   • Adjusting pH (using acid to lower the pH as low as 5.5)
38
39   • Improving mixing or applying moderate dosage of an oxidant
40
41   As one part of the treatment process is modified, PWSs should consider the impacts on
42   subsequent processes and within the distribution system. Systems considering whether enhanced

coagulation may be an effective way to reduce DBPs should refer to the *Guidance Manual for Enhanced Coagulation and Precipitative Softening* (USEPA 1999h).

This section discusses the advantages and disadvantages of enhanced coagulation, and provides recommendations for how systems may be able to address and minimize the disadvantages.

3.7.1   Advantages of Enhanced Coagulation

Some advantages to enhanced coagulation include:

- **May improve disinfection effectiveness**

- **Can reduce DBP formation**

- **Can reduce bromate formation**

- **Can enhance arsenic and radionuclide removal**

Improved Disinfection Effectiveness

Conventional filtration plants must achieve a 3.0 log *Giardia* removal/inactivation and 4.0 log virus removal/inactivation. Enhanced coagulation can improve disinfection effectiveness in three ways:

- Lower the pH during disinfection
- Reduce disinfectant demand
- Remove particles to which pathogens are attached

The pH may be suppressed artificially using an acid or may be the result of heavy alum or ferric coagulant doses.

Chlorine is pH-sensitive, being more effective at low pH values (see Section 3.2 for a more complete discussion of chlorine sensitivity to pH). Therefore, a decrease in pH results in greater inactivation of *Giardia* and viruses. Ozone also exhibits increased performance at lower pH values (Carlson et al. 2000). Conversely, chlorine dioxide can be less effective at low pH values.

The removal of NOM through enhanced coagulation may allow increased disinfectant efficiency by decreasing the demand on the disinfectants exerted by organics (Carlson et al. 2000). For a system to realize this benefit, the system should inject the disinfectant at a location in the treatment process where NOM removal has been achieved. This operational scenario may

1   allow the system, in consultation with their regulatory agency, to reduce the amount of
2   disinfectant used compared to dosages required prior to practicing enhanced coagulation. A
3   reduction in the amount of disinfectant applied should result in fewer DBPs being formed. The
4   system should, however, ensure that the necessary microbial inactivation is maintained at all
5   times by measuring:
6
7   • the disinfectant residual
8   • flow, temperature, and pH
9   • calculating the resulting inactivation contact times and CTs being achieved
10
11   By increasing the removal of particles and organic matter, pathogens that are attached to
12   these substances will also be removed.
13
14   *Reduced DBP Formation*
15
16   Enhanced coagulation improves the removal of DBP precursors in a conventional water
17   treatment plant. The removal of TOC (a surrogate measure of NOM) by coagulation has been
18   demonstrated in several laboratory research, pilot demonstrations, and full-scale studies
19   (Chowdhury et al. 1997, Edwards 1997). Removal of TOC can result in a decrease in TTHM
20   and HAA5 formation. In fact, the Stage 1 D/DBPR uses TOC to define enhanced coagulation
21   for DBP precursor removal requirements.
22
23   A reduction in pH has also been demonstrated to result in a reduction in formation of
24   chloroform (Singer 1999). A more detailed discussion of this topic is provided in Section 3.4.
25
26   *Reduced Bromate Formation*
27
28   The reduction of pH that may be practiced as part of enhanced coagulation can result in
29   better control of bromate formation for those systems using ozone. Williams et al. (2003)
30   indicated that a pH of about 6.5 provided effective reduction of bromate formation. The
31   effectiveness of bromate control at lower pH values depends on the source water, particularly its
32   alkalinity.
33
34   *Arsenic and Radionuclide Removal*
35
36   Compliance with the new arsenic maximum contaminant level (MCL) of 0.010 mg/L
37   may require systems to consider treatment modifications for improved arsenic removal. Some
38   systems may realize improved arsenic removal by using a ferric coagulant as part of the
39   enhanced coagulation process. Scott et al (1995) observed that arsenate (As(V)) removal was in
40   the range of 80 to 95 percent for a ferric coagulant dose ranging from 3 to 10 mg/L. Alum
41   coagulation has been shown to remove arsenic, but at higher doses (up to 20 mg/L)   Removal of
42   arsenite (As(III)) is much less efficient than As(V), though iron coagulants are still more

1   effective at removing As(III) than alum coagulants (Hering et al. 1996; Edwards et al.1994).
2   Modified coagulation is identified by EPA as a Best Available Technology (BAT) for the
3   Arsenic Rule.
4
5   Enhanced coagulation may also provide better radionuclide removal since radionuclides,
6   such as uranium, have been shown to be removed by coagulation/filtration (Sorg 1988). Systems
7   will want to understand fully their requirements for disposal of residuals containing
8   radionuclides and check with their State or Primacy Agency for instructions on special handling
9   or disposal of residuals containing radionuclides.
10

11 **3.7.2   Potential Operational and Simultaneous Compliance Issues Associated with**
12 **Enhanced Coagulation**
13
14   Potential issues associated with enhanced coagulation include:
15

16 •   **Adverse impacts to finished water turbidity**
17

18 •   **Corrosion concerns**
19

20 •   **Increased concentrations of inorganics in the finished water**
21

22 •   **Additional issues with residual disposal**
23

24 This section discusses these issues briefly and provides suggestions for reducing their impacts.
25

26 *Finished Water Turbidity*
27

28   In most cases, lowering the pH and/or increasing coagulant feed will result in lowering
29 turbidity in the finished water. However, lower pH levels can sometimes lead to the formation of
30 a less dense, more fragile floc. This type of floc can carry over from the clarifier and may result
31 in shorter filter run times or premature filter breakthrough (Singer 1999). A lower pH and higher
32 coagulant dose may also result in restabilization of particles. These conditions can create upsets
33 in solids blanket-type clarifiers (Carlson et al. 2000).
34
35   Premature filter breakthrough as a result of higher particle loading to the filter could
36 result in shorter filter runs or, if a system does not adjust its operations in response to the higher
37 particle loading, the system might not meet the turbidity limits established by the IESWTR and
38 LT1ESWTR. This may also trigger individual filter follow-up actions as required by IESWTR
39 and LT1ESWTR. Conversely, enhanced coagulation may have a positive effect on subsequent
40 treatment steps, resulting in lower finished water turbidity, potentially longer filter runs, and
41 better compliance with effluent turbidity limits.
42

1   <u>Recommendations for Addressing this Issue</u>
2
3   Systems may want to pilot test different coagulants to identify the coagulant type and
4   dose that produces the most stable, settleable floc. Lovins et al. (2003) found that ferric sulfate
5   produced a larger, more durable and more settleable floc relative to alum in Peace River water, a
6   high DOC water, at a pH of around 7.5.
7
8   Systems should consult the "Enhanced Coagulation and Enhanced Precipitative Softening
9   Guidance Manual" (USEPA 1999h) for recommendations on how to maintain low turbidity
10   while performing enhanced coagulation.
11
12   *Corrosion Concerns*
13
14   Corrosion control within the distribution system can be affected by a change in pH,
15   change in the chloride to sulfate ratio, change in organics concentration, or a significant change
16   in the alkalinity of the finished water (Carlson et al. 2000). Any of these conditions can occur as
17   a result of enhanced coagulation and can potentially create compliance issues with the LCR.
18
19   Enhanced coagulation lowers TOC. Changes in TOC have been found to have differing
20   impacts on corrosion. Schock et al. (1996) found that in some cases, NOM can form soluble
21   complexes with lead which can increase corrosion. In other cases, NOM was found to coat the
22   pipes and lower corrosion rates. Edwards et al. (1996) have reported similar results for copper
23   corrosion. Edwards et al. (2004) found that lower TOC in combination with higher aluminum
24   may cause pinholes leaks in copper piping.
25
26   Enhanced coagulation can lower alkalinity. The effect of an alkalinity change depends
27   on the initial alkalinity; for water with moderate to low alkalinity, a decrease in alkalinity can
28   increase corrosion. Systems are encouraged to maintain a minimum alkalinity of 10 to 20 mg/L
29   as calcium carbonate. If the initial alkalinity is high, however, a decrease may be beneficial
30   since a decrease in alkalinity can also decrease copper corrosion rates.
31
32   Enhanced coagulation lowers pH. Lower pH generally increases corrosion rates.
33   Changing distribution system pH can also alter the condition of pre-existing scale. The lower the
34   initial pH, the smaller the pH change needed to affect the corrosion rate. At an initial pH of 7, a
35   pH change of 0.2 can affect corrosion, while with an initial pH of 9 it takes a pH change of over
36   0.5 to significantly affect corrosion. Softened scale can break off and entrain materials contained
37   in it into the distribution system.
38
39   Lower pH can also have adverse impacts within the treatment plant. Cement can degrade
40   in acidic conditions. Metals in pipes and pumps may also be susceptible to corrosion.
41

1   If aluminum coagulants are used and overdosing occurs, efforts to perform enhanced
2   coagulation may result in increased aluminum concentrations. Aluminum can increase corrosion
3   of lead and copper, though it will decrease corrosion of copper byproducts.
4
5   The increased use of coagulants in enhanced coagulation will raise the concentration of
6   the anion, either sulfate or chloride, and will affect the chloride to sulfate ration. A low chloride
7   to sulfate ratio has been shown to decrease corrosion rates (Edwards et al.1999).
8
9   Recommendations for Addressing this Issue
10
11   Systems should consider adjusting their pH upward before the water enters the
12   distribution system in order to reduce corrosion of pipe materials. Systems will want to identify
13   the optimum pH within the distribution system that
14   enables compliance with the LCR and does not result
15   in substantial increases in DBP levels. If the system
16   cannot readjust the pH to a high enough level using
17   caustic to prevent corrosion, it can consider adding a
18   corrosion inhibitor (i.e., a substance that is phosphate-
19   or silica-based) to the finished water to form a protective coating on the pipes.
20

> **Water systems should carefully research the implications of using a corrosion inhibitor before adding it as a treatment step.**

21   Water systems should carefully research the implications of using a corrosion inhibitor
22   before adding it as a treatment step. Some utilities have elected not to use phosphate-based
23   corrosion inhibitors because the POTW receiving the wastewater violated phosphorus limits in
24   their disposal permits. Zinc toxicity to wastewater treatment biota can also be a concern. Lime
25   addition can potentially cause turbidity problems if the dosing and mixing are not done properly.
26   Conversely, research has shown that corrosion control often has the added benefit of controlling
27   biological growth in the distribution system, which can lead to improved compliance with the
28   TCR.
29
30   Regardless of the type of corrosion inhibitor used, it should be carefully pilot tested
31   before it is introduced. Large water systems were required to conduct corrosion control studies
32   under the LCR. Smaller systems may have conducted studies if required by the state. Any
33   system that subsequently changes their treatment must notify the state and may be required to
34   conduct a new corrosion control study. In any event, LCR corrosion control studies should be
35   used as a starting point to assess the impacts of changes in distribution system water quality on
36   corrosion and LCR compliance and determine the best corrosion control treatment strategy.
37   Appendices C and D provide additional guidelines for systems evaluating their corrosion control
38   options and information on proper piloting procedures.
39
40   Systems should also monitor inside the plant for signs of corrosion of cement or metal. If
41   corrosion is noticed, corrosion may be prevented by applying an epoxy coating. For metals such
42   as pipes and pumps, using a sacrificial anode is an option in addition to epoxy coatings. Exterior
43   fittings in buildings should be painted to reduce corrosion. Finally, when designing new

1   processes materials compatible with the anticipated pH and water quality in the plant should be
2   specified.
3
4   *Increased Inorganics in Finished Water*
5
6   Enhanced coagulation can cause an increase in inorganics, such as manganese,
7   aluminum, sulfate, chloride, and sodium, in the finished water. The low pH that frequently
8   results from enhanced coagulation reduces the oxidation rate of manganese from the dissolved
9   state (Mn^{2+}) to the solid form (MnO_2) that allows it to be removed during sedimentation and
10 filtration. Ideally, manganese is completely oxidized before the coagulation step, and enhanced
11 coagulation should not deter manganese removal. Systems should note, however, that even very
12 low concentrations of manganese (e.g., 0.05 mg/L) in the finished water could result in aesthetic
13 problems.
14
15   Manganese may also be present in concentrations above the secondary standard of 0.05
16 mg/L if high dosages of ferric coagulants are used (Carlson et al. 2000). Ferric chloride and
17 ferric sulfate coagulants can contain relatively high concentrations of manganese. If a water
18 system switches from low doses of ferric or alum to high doses of ferric, the coagulant itself may
19 significantly increase the amount of dissolved manganese in the water.
20
21   The presence of high concentrations of sulfate or chloride may affect the corrosivity of
22 the water (Carlson et al. 2000). The mass ratio of chloride to sulfate can also affect the
23 corrosivity of the water. Edwards et al. (1999) found that of 24 utilities surveyed, none of the
24 utilities with a chloride to sulfate ratio of less than 0.58 exceeded the lead action level, while 64
25 percent of utilities with a ratio greater than 0.58 exceeded the lead action level.
26
27   Increased aluminum in the distribution system may result when high alum dosages are
28 used in an effort to perform enhanced coagulation. Increased aluminum can lead to aesthetic
29 problems, such as solids precipitation, in the distribution system (Carlson et al. 2000). Increased
30 alum can be kept from passing through filters by addition of filter aids and more frequent
31 backwashing. More frequent backwashing, however, has costs and other implications.
32
33   Recommendations for Addressing this Issue
34
35   System operators should consider their source water specifically when making choices
36 about coagulant use. Systems should jar test and, ideally, pilot test under different water quality
37 conditions the coagulants that they are considering before making full-scale coagulant treatment
38 changes. NSF and manufacturer recommendations should be followed in coagulant dosing.
39 Specifications for coagulants and other treatment chemicals should also specify allowable
40 concentrations of trace contaminants. Section 6.3 describes some ways systems can test their
41 water to determine which coagulant is best suited for their water quality and particular treatment
42 needs. Systems with a high chloride to sulfate ratio may be able to mitigate corrosion by
43 switching from a chloride-based coagulant to a sulfate-based coagulant.

Residuals Handling

Because more coagulant is added and more organics are being removed, enhanced coagulation will likely result in the production of more waste residuals. The conditions for existing disposal of water treatment plant (WTP) sludge should be reviewed and even renegotiated, and increased costs of waste disposal should be factored into a system's decision.

If the source water has high concentrations of hazardous contaminants such as arsenic or radionuclides, the waste residuals may concentrate these contaminants to the extent that the waste is considered unfit for disposal in a sanitary landfill. States have limits on toxics concentrations in waste residuals disposed of in sanitary landfills, and exceeding any of those limits could cause the waste to be classified as hazardous. In addition, some states have additional disposal requirements for residuals that have been characterized as technologically enhanced naturally occurring radioactive material (TENORM) that can further complicate disposal.

Recommendations for Addressing this Issue

Systems will likely experience higher costs with managing an increased residual load. Depending on how residuals are managed, additional facilities may need to be constructed or new permits may be necessary. Aluminum is toxic to aquatic life, so increased alum use may result in limitations on the discharge of the residual stream to surface water bodies.

Systems should properly analyze the sludge that results from enhanced coagulation for increased metals and other contaminants that may create issues with final sludge disposal. The regulatory agency should be consulted regarding disposal of residuals if hazardous chemicals are concentrated in the residuals. EPA has recently released *A Regulator's Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies*, (USEPA 2005c) which deals with the issue of radioactive compounds concentrated in residuals.

Typically, ferric sulfate sludges are more easily dewatered as compared to alum sludges (Thompson et al. 1998).

3.7.3   Recommendations for Gathering More Information

Read the Case Studies

Three case studies in Appendix B describe simultaneous compliance challenges faced by utilities using enhanced coagulation.

Case Study #4 Switching Coagulants starting on page B-25 describes how a system could simultaneously comply with the TOC removal requirements of the Stage 1 D/DBPR and

1   the turbidity removal requirements of the IESWTR by switching coagulants. The system found
2   that enhanced coagulation with ferric sulfate not only increased TOC removal significantly, but
3   also reduced turbidity levels in the finished water. The major problem experienced in
4   implementing the treatment modification was the control of manganese and corrosion in the
5   rapid mix chamber due to the addition of sulfuric acid.
6
7   ***Case Study #5 Enhanced Coagulation-Problems with Copper Pitting*** starting on page
8   B-33 describes a system that experienced pinhole leaks in their copper piping following
9   alterations to the coagulation process. The system implemented orthophosphate addition to
10 address the pinhole leaks, which also had an effect on finished water turbidity and iron release
11 from unlined cast iron mains.
12
13   ***Case Study #6 Enhanced Coagulation - Managing Radioactive Residuals*** starting
14 on page B-39 provides a discussion of a system's options for disposing of radioactive
15 residuals resulting from enhanced coagulation. As a result of enhanced coagulation,
16 radionuclides can become concentrated in residuals at levels that require special
17 consideration for regulatory approval of sludge disposal.
18
19 *See Additional References*
20
21   Readers can turn to Section 7.1.8 in Chapter 7 for technical references associated with
22 using enhanced coagulation.
23
24 *Consider Additional Monitoring*
25
26   The following are some suggestions for additional monitoring that may benefit water
27 systems using enhanced coagulation:
28
29 ✓ Routine turbidity or particle count monitoring of water leaving the sedimentation basin to
30   ensure that a consistently stable and dense floc is forming.
31
32 ✓ Routine finished water pH and alkalinity monitoring to help ensure that corrosion control
33   is being implemented correctly.
34
35 ✓ Periodic aluminum measurements in the finished water to watch for aluminum carryover
36   from the combination of alum floc and low pH.
37
38 The purpose of these monitoring suggestions is specifically to address and prevent potential
39 simultaneous compliance issues.
40

1   *Consider Other Tools*
2
3   In addition to water quality monitoring, there are additional tools available in Chapter 6
4   to help systems evaluate and improve their current water system in relation to the compliance
5   issues they may face when modifying their operation or treatment practices. Examples of tools
6   that can be used when enhanced coagulation is used for Stage 2 DBPR compliance include:
7
8   • The "Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual"
9   (U.S. EPA 1999h) that provides procedures for conducting jar testing to determine the
10   optimum coagulation conditions for achieving desirable total organic carbon removal
11   and coagulated/settled water turbidity
12
13   • The AwwaRF report "Internal Corrosion of Water Distribution System" (AWWARF
14   and DVGW-Technologiezentrum Wasser 1996), which provides bench-scale and
15   pilot testing protocols that can be used to evaluate changes in corrosion potential due
16   to changes in pH
17
18   • The "Guidance Manual for Monitoring Distribution System Water Quality"
19   (Kirmeyer, 2002) which can be used to assist water utilities in implementing a
20   distribution system water quality data collection and analysis program
21
22   • The second version of "Water Treatment Plant Model" (U.S. EPA 2001h) developed
23   by USEPA that assists utilities with implementing various treatment changes while
24   maintaining adequate disinfection and meeting the requirements of Stage 2 DBPR.
25
26   Readers are encouraged to read through Chapter 6 before making any final compliance decisions.
27
28

3.8   Enhanced Softening

Precipitative softening with lime addition is typically practiced with the objective of removing hardness in the form of calcium and magnesium from water. Total hardness removal goals vary between treatment plants. Lime softening processes are generally divided into three distinct groups:

- Conventional lime softening to remove calcium carbonate where only lime is fed

- Lime-soda softening to remove calcium carbonate and noncarbonate hardness by feeding both lime and either soda ash or potassium carbonate

- Excess lime softening to remove both calcium and magnesium (and sometimes silica) by adding an excess of lime

All softening plants operate at higher pH levels than conventional coagulation plants. Calcium carbonate begins to precipitate above pH of 9.5 and as the pH increases above 10, magnesium hydroxide precipitation increases.

Softening has some similarities to coagulation with respect to the mechanisms operating to remove particles and TOC, so that when coupled with appropriate settling, DBP precursors can be removed effectively by softening. Generally, removal of TOC in softening is enhanced by the addition of a small amount of coagulant. The regulatory requirement for enhanced softening in the Stage 1 D/DBPR is based on the assumption that raising the lime dose will foster the precipitation of $CaCO_3$ and the associated coprecipitation of precursors. The resulting increase in pH causes increased precursor removal, presumably by promoting stronger interactions between the precursors and calcium ions. In addition, the increase in pH may be sufficient to precipitate magnesium hydroxide, which strongly adsorbs precursors (Randtke 1999, Shorney and Randtke 1994).

> **Generally, removal of TOC in softening is enhanced by the addition of a small amount of coagulant.**

When the pH of softening is changed significantly, differences in process chemistry affect the nature of the solids that are formed with respect to settling and dewatering characteristics. Enhanced softening criteria do not require plants to alter the softening process to the extent that major changes in settling conditions and solids handling are generally required. A plant is considered to be practicing enhanced softening if it meets the appropriate TOC removal target in the 3x3 TOC removal matrix. Most softening plants have raw water alkalinity above 120 mg/L as $CaCO_3$, so that they are classified in the right hand column of the matrix, but a few fall into the classification for influent with alkalinity of 60 – 120 mg/L. Plants that cannot meet the removal requirements in the 3x3 matrix may remain in compliance by removing a minimum

1   of 10 mg/L of magnesium as CaCO$_3$. Alternatively, softening plants that reduce their finished
2   water alkalinity to 60 mg/L are in compliance with enhanced softening.
3
4   **3.8.1   Advantages of Enhanced Softening**
5
6   The main advantages of enhanced softening are:
7
8   ◆   **Adequate removal of TOC**
9
10   ◆   **Two stage plants may achieve additional *Cryptosporidium* removal credit**
11
12   ◆   **Lower corrosion impacts**
13
14   *Adequate Removal of TOC*
15
16   Softening plants typically do not have difficulty meeting the TOC removal requirements
17   of the 3x3 matrix in the Stage 1 D/DBPR. Information from a survey of softening plants (1999)
18   indicated that operational data showed TOC being removed at least at the level defined by the
19   matrix, and this fact is substantiated by the data from the Information Collection Rule (ICR).
20   Since plants were not necessarily striving to meet the enhanced softening criteria during the ICR
21   sampling period, apparently the standard operating scheme for most softening plants actually
22   falls within the criteria of "enhanced softening" as defined by the rule (Clark et al. 2002).
23
24   The only instances reported by softeners which lead to difficulty in removing TOC occur
25   when raw water alkalinity drops significantly causing the calcium hardness:carbonate alkalinity
26   ratio to be elevated. This situation can arise when surface water is diluted by major rain events
27   or when a blend of ground and surface water is altered in proportions. In these cases, some
28   addition of carbonate alkalinity in the form of soda ash or potassium carbonate may be warranted
29   to facilitate the softening reactions and the coprecipitation of organic material. Softening utilities
30   are expected to be able to meet the requirements of the Stage 2 DBPR as effectively, or more so,
31   as conventional coagulation plants (USEPA 2003a).
32
33   *Two Stage Plants May Achieve Additional Cryptosporidium Removal Credit*
34
35   Plants that include a two-stage lime softening process are eligible for an addition 0.5-log
36   *Cryptosporidium* removal credit toward compliance under the proposed LT2ESWTR (USEPA
37   2003a). The two-stage process must consist of a second clarification step between the primary
38   clarifier and filters that is operated continuously. Both clarifiers must treat all of the plant flow
39   and must contain a coagulant, which can be lime, magnesium hydroxide or a metal coagulant.
40   Refer to the *Draft LT2ESWTR Toolbox Guidance Manual* (USEPA 2003a) for additional
41   requirements for receiving this credit.
42

1 *Lower Corrosion Impacts*
2
3   Softening systems have an advantage with respect to managing corrosion for two reasons.
4 Since the softening process takes place at a pH above 10, systems generally add carbon dioxide
5 to reduce pH and stabilize the water prior to distribution. Selection of an appropriate finished
6 water pH goal takes into consideration the optimum pH for corrosion control. At the same time,
7 softening systems generally produce water that tends to develop scale in the distribution system.
8 If the scale formation is not managed appropriately, it can be a liability with respect to flow
9 restriction, but from a corrosion control standpoint, scale formation is a distinct benefit.
10
11   As noted in EPA's "Enhanced Coagulation and Enhanced Precipitative Softening
12 Guidance Manual" (USEPA 1999h), the information in Exhibit 3.6 is intended only to
13 characterize existing and future corrosion control strategies. The figure can be used proactively
14 to anticipate problems that may develop if enhanced softening is used.
15
16
17 **Exhibit 3.6 Effect of the Change of Water Quality Parameters Due to Enhanced**
18 **Softening on Corrosion of Piping System Materials**
19

Parameter	Potential Change Resulting From Enhanced Softening		Impact on Corrosion of Material				
			Pb	Cu	Fe	Pb from Brass	Concrete
TOC	▼		►	► ▼[2] [1]	▼	▼ ►	▲
Alkalinity	▼	►	►	►	▲ ►	▼ ►	▲ ►
Ca Hardness	▼		►	►	▲ ►	►	▲
pH	▲	►	▼ ►	▼ ►	▼ ►	▼ ►	►
Sulfate	►		►	►	►	►	►
Chloride	►		►	►	►	►	►
[1] applies to copper [2] applies to copper by-products	► = decrease		▲ = increase			► = same (no change)	

20
21 Source: EPA's Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual (USEPA 1999h)
22
23

1   **3.8.2   Potential Operational and Simultaneous Compliance Issues Associated with**
2   **Enhanced Softening**
3
4   Potential issues associated with enhanced softening include:
5
6   ◆   **Options for disinfection are limited**
7
8   ◆   **Higher TTHM formation at high pH**
9
10   ◆   **Can cause scaling**
11
12   ◆   **pH adjustment required for distribution and for disinfection effectiveness**
13
14   ◆   **Increased sludge volume and changes in sludge characteristics**
15
16   This section briefly describes these issues and provides suggestions for minimizing their impacts.
17
18   *Options for Disinfection Are Limited*
19
20   One of the most complex issues facing softening plants with respect to regulatory
21   compliance is selection and implementation of disinfection processes. Disinfection with
22   chlorine, chloramines, chlorine dioxide, and ozone requires specific consideration of issues that
23   arise in high pH waters.
25
27   Based on data from an AWWA survey
29   of softening plants completed in 1997 to inform
31   the regulatory development process, more than
33   one third of softening plants predisinfect with
35   chlorine, ozone, or a combination of
37   chlorine/chloramines and they take CT credit
39   for some or all predisinfection contact time. In

Disinfection credit using chlorine or chloramines through the softening portion of the treatment process must be evaluated on a case-by-case basis by the primacy agency.

40   addition, the survey indicated that the finished water pH in softening plants ranges from 7.5 to
41   10, with approximately half reporting average finished water pH greater than 9. CT values for
42   inactivation of *Giardia* by free chlorine and chloramines are not identified for pH levels greater
43   than 9 in the SWTR Guidance (USEPA 1991). Thus, disinfection credit using chlorine or
44   chloramines through the softening portion of the treatment process must be evaluated on a case-
45   by-case basis by the primacy agency. Some softening plants have resolved this problem by
46   providing appropriate contact time after softening and pH reduction to meet required CT values
47   with their selected disinfectant.
48
49   Use of chlorine dioxide in softening plants is governed by the regulated levels for
50   chlorine dioxide and chlorite. Chlorine dioxide reacts with many organic and inorganic
51   constituents in water. It disinfects by oxidation, but does not chlorinate. Chlorine dioxide

1   functions as a highly selective oxidant due to its unique, one-electron transfer mechanism where
2   it is reduced to chlorite. The reactions produce chlorite and chlorate as endpoints. In drinking
3   water, chlorinate (ClO_2^-) is the predominant reaction endpoint, with approximately 50 to 70
4   percent of the chlorine dioxide converted to chlorite and 30 percent to chlorate (ClO_3^-) and
5   chloride (Cl^-) (USEPA 1999). The balance between these two species varies frequently and is
6   affected by the exposure to bright sunlight, aeration, and recarbonation, among other factors
7   (Gates 1997). The disproportionation of ClO_2 is accelerated by increased pH, which means that
8   the addition of lime soon after the addition of ClO_2 may result in minimal disinfection time and
9   development of both chlorite and chlorate (Hoehn 1993). There may be situations in which
10   chlorine dioxide can be used as a preoxidant in softening plants, but they would be governed by
11   the contact time available prior to the addition of lime and initiation of the softening process.
12
13   Ozone use at high pH (above pH = 7) will form significant bromate when bromide is
14   present in the water. Ozonation at lower pH can control the formation of bromate, but will
15   increase the formation of brominated organic byproducts produced from the interaction between
16   hypobromous acid and NOM, producing an overall increase in TTHMs by weight (Reckhow
17   1999). In softening plants, the use of ozone generally requires reduction of pH from the
18   softening pH (between 10 and 11) to a pH between 6 and 7. To obtain such a shift in pH,
19   significant amounts of acid are often consumed. Thus, unless a unique water quality concern
20   requires use of ozone, other disinfection options should be considered.
21

Higher THM Formation

22
23
24   THM formation has been shown to be higher with increasing chlorination pH, while
25   some of the HAAs appear to have lower formation at higher pH (Krasner 1999). A number of
26   softening plants have constructed a large chlorine contact chamber/clearwell to provide
27   disinfection contact time after the pH of the water is lowered from the softening pH to a pH that
28   minimizes DBP production.
29
30   Many raw water sources that are treated by softening contain significant levels of
31   bromide. As plants practice enhanced softening to remove precursors, the ratio of the amount of
32   bromide in the water to the amount of TOC goes up because bromide is not removed by
33   softening. Research has shown that as the ratio of bromide to TOC increases the percentage of
34   brominated DBPs increases. Thus, when bromide-containing enhanced softened water is
35   disinfected with chlorine, formation of brominated THMs increases, resulting in a higher total
36   weight of THMs formed. Thus, softening plants may be forced into a balancing of TOC removal
37   with DBP formation to optimize the finished water DBP formation based on speciation of the
38   THMs and total weight of TTHMs.
39
40   <u>Recommendations for Addressing this Issue</u>
41
42   If softening plants have problems complying with the proposed Stage 2 DBPR TTHM
43   MCLs, three possible alternatives should be considered.

1
2 • Systems may be able to reduce finished water pH somewhat to reduce the TTHM
3   formation potential in the system. Changes in system pH should be cautiously
4   undertaken to ensure that the existing system scale is not altered significantly,
5   softened, or stripped from pipes, thereby causing major operational problems.
6
7 • Systems may be able to utilize alternative disinfectants, including chloramines,
8   chlorine dioxide, or ozone. Chloramines are best suited for use as a distribution
9   system residual although some softening plants operate with a chloramine residual
10   carried through the softening process. Chlorine dioxide and ozone disinfection must
11   be evaluated with care in both quantity and placement to ensure that neither chlorate
12   nor bromate MCLs are violated. Use of UV for disinfection may reduce the level of
13   chlorine or chloramine residual required for residual disinfection in the distribution
14   system.
15
16 • Softening plants may also evaluate the possible conversion from conventional
17   softening to membrane softening. The use of microfiltration followed by
18   nanofiltration can remove TOC as well as provide softened water, thereby reducing
19   the DBP formation potential. Cost may be a factor that prohibits a system from
20   making this change. In addition, membrane conversion can necessitate the need to
21   consider other simultaneous compliance issues such as ensuring that distribution
22   system chemical equilibrium is not altered in a way that will cause either corrosion or
23   scale sloughing.
24
25 *Scaling*
26
27   Depending on the raw water quality and the physical configuration of the treatment
28 processes in a softening plant, the addition of extra lime to provide enhanced softening
29 conditions can lead to increased scaling conditions in both the treatment plant and the
30 distribution system piping. In general, if the Langelier Saturation Index (LSI) is positive, the
31 water is oversaturated with $CaCO_3$ and has the potential to precipitate and form scale.
32
33 *pH Adjustment Required for Distribution and for Disinfection Effectiveness*
34
35   Most softening plants adjust pH to meet finished water pH goals, to meet pH
36 requirements for disinfection effectiveness after the completion of the softening process, and to
37 satisfy distribution system chemical equilibrium. As the pH of softening is increased in an effort
38 to remove more TOC, the quantity of chemical required for pH adjustment increases.
39 Historically, the finished water pH in softening plants has ranged between 7.5 and 10.
40

1   *Increased Sludge Volume and Changes in Sludge Characteristics*
2
3   Significant increases in lime doses will result in increased lime sludge production.
4   Residuals production may also increase when lime addition results in a pH greater than 10.25 in
5   plants with significant magnesium present that have not historically softened at pH greater than
6   10. At that pH, the magnesium hydroxide is precipitated along with calcium carbonate. If
7   significant noncarbonate hardness exists, then addition of soda ash may be necessary, resulting in
8   increased residuals production and higher sodium levels in the finished water. In addition, the
9   handling and dewatering characteristics may be significantly altered (Randtke 1999).
10
11   In the softening process, calcium carbonate forms a dense crystal that is negatively
12 charged, while magnesium hydroxide forms large, light floc that has a high surface area and
13 positive surface charge. This difference in particle characteristics is what makes magnesium
14 hydroxide a better adsorbent for dissolved precursors; however magnesium hydroxide solids
15 have settling and dewatering characteristics that are quite different from calcium carbonate
16 solids. In fact, softening plants that are designed to settle calcium carbonate may very well have
17 inadequate settling time to settle magnesium hydroxide. If the previous softening pH was less
18 than 10.25 and the water has significant magnesium, then enhanced softening in which the pH is
19 increased to greater than 10.25 can cause formation of magnesium hydroxide, which may not be
20 effectively removed in the settling process, or may change the characteristics of the process
21 solids.
22
23 **3.8.3   Recommendations for Gathering More Information**
24
25 *See Additional References*
26
27   Readers can turn to Section 7.1.8 of Chapter 7 for technical references associated with
28 enhanced softening
29
30 *Consider Additional Monitoring*
31
32   The following are some suggestions for additional monitoring that may benefit softening
33 systems. The purpose of these monitoring suggestions is specifically to address and prevent
34 potential simultaneous compliance issues.
35
36   ✓ Routine LSI measurements, or another comparable calcium carbonate saturation index, of
37   water entering the distribution system to monitor the potential for excess scale formation.
38   Weekly measurements may be sufficient when raw water quality is relatively consistent.
39   More frequent checks may be useful under changing raw water conditions.
40

1   *Consider Other Tools*
2
3   In addition to water quality monitoring, there are additional tools available in Chapter 6
4   to help systems evaluate and improve their current water system in relation to the compliance
5   issues they may face when modifying their operation or treatment practices. Examples of tools
6   that can be used when enhanced softening is used for Stage 2 DBPR compliance include:
7
8   •   The "Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual"
9   (U.S. EPA 1999h) that provides procedures for conducting jar testing to determine the
10   optimum coagulation and softening conditions for achieving desirable total organic
11   carbon removal and coagulated/settled water turbidity
12
13 •   The AwwaRF report "Internal Corrosion of Water Distribution System" (AWWARF
14   and DVGW-Technologiezentrum Wasser 1996) which provides bench-scale and pilot
15   testing protocols that can be used to evaluate changes in corrosion potential due to
16   changes in pH
17
18 •   The "Guidance Manual for Monitoring Distribution System Water Quality"
19   (Kirmeyer 2002) which can be used to assist water utilities in implementing a
20   distribution system water quality data collection and analysis program
21
22 •   The second version of "Water Treatment Plant Model" (U.S. EPA 2001h) developed
23   by USEPA that assists utilities with implementing various treatment changes while
24   maintaining adequate disinfection and meeting the requirements of Stage 2 DBPR.
25
26 Readers are encouraged to read through Chapter 6 before making any final compliance decisions.
27
28

1
2
3   **4 Installing New Total Organic Carbon or**
4   **Microbial Removal Technologies**
5
6
7
8   Some water systems will choose to install a new type of treatment in order to comply
9   with the Stage 2 Disinfectants and Disinfection Byproducts Rule (DBPR) and/or the Long Term
10   2 Enhanced Surface Water Treatment Rule (LT2ESWTR). This chapter describes treatment
11   technologies that can be installed to remove disinfection byproduct (DBP) precursors and
12   microbial pathogens. Advantages of using each treatment are described, along with summaries
13   of operational and simultaneous compliance issues associated with the treatment. General
14   recommendations for addressing those issues are also provided.
15
16   While most of the issues presented in the following sections address simultaneous
18   compliance concerns, some
20   additional operational and aesthetic
22   issues are discussed. Each   **TREATMENTS COVERED**
24   technology includes a section with
26   recommendations for gathering   • Granular Activated Carbon
28   more information.
30   • Microfiltration/Ultrafiltration
32   **4.1   Granular Activated**
34   **Carbon**   • Nanofiltration

                                            • Other Microbial Removal Technologies
36
37   The main benefit of granular activated carbon (GAC) is that it is effective in adsorbing
38   and removing organic compounds from water. Removing organic matter prevents it from
39   forming DBPs, causing taste and odor complaints, and stimulating microbial activity in the
40   distribution system. Additionally, if GAC is used in series with a conventional filter, systems
41   may be able to receive additional *Cryptosporidium* removal credit under the LT2ESWTR. The
42   main drawbacks to using GAC are the possibility of release of bacteria or carbon fines into the
43   system, the possibility of chromatographic peaking, and its reaction with disinfectants. These
44   issues are discussed in more detail in Section 4.1.2.
45
46   GAC can be used as an additional layer on top of an existing filter (GAC cap), or it can
47   be placed in a separate contactor. Design will vary depending on whether it is used as a separate
48   adsorber or if it is added as a filter cap. Its efficiency is determined by the contact time and the
49   relative adsorption strength of the compounds that are to be removed. Some physical removal by
50   filtration will occur in GAC beds as well.
51

1   **4.1.1   Advantages of GAC**
2
3   The advantages of GAC include:
4
5   • **Removes DBP precursors through adsorption**
6
7
8   • **Can remove taste and odor compounds**
9
10   • **If used as a secondary filter, the system may be able to receive a 0.5-log**
11   ***Cryptosporidium* removal credit**
12
13   • **Can be used as a biologically active filter after ozone to remove assimilable**
14   **organic carbon (AOC)**
15
16
17 *DBP Precursor Removal*
18
19   DBP precursor removal before the addition of a disinfectant can significantly lower DBP
20 production and ease compliance with the Stage 2 DBPR. GAC10, a GAC contactor with a 10
21 minute empty bed contact time (EBCT), is considered a best available technology (BAT) for the
22 Stage 1 Disinfectants/Disinfection Byproducts Rule (D/DBPR). GAC10 in combination with
23 enhanced coagulation or enhanced softening or GAC20 are considered BATs for the Stage 2
24 DBPR. GAC has been found to reduce total organic carbon (TOC) by 30 to 90 percent
25 depending on the contact time, the nature of the organic matter, and other parameters (USEPA
26 2005d). Generally, AOC is removed relatively quickly while other organic fractions take longer
27 to remove.
28
29 *Taste and Odor Removal*
30
31   Because many taste and odor compounds are organic, the ability of GAC to adsorb
32 organics also makes it a useful treatment technique in this respect. For example, GAC has been
33 found to remove 30 to 40 percent of geosmin from drinking water (Youngsug et al. 1997). The
34 removal efficiency was increased to 80 percent or more with the addition of ozone or ozone
35 peroxide. Similar reductions can be achieved for 2-methylisoborneol (MIB).
36
37 *Cryptosporidium Removal*
38
39   Systems can receive a 0.5-log *Cryptosporidium* removal credit for having a second set of
40 filters in series in a conventional treatment plant. Both a GAC contactor and a conventional dual
41 media filter with a GAC cap are eligible for this credit. In both cases the *Cryptosporidium* is
42 removed through physical filtration onto the filter media. The GAC filter must treat the entire
43 flow of the plant to obtain the credit. Refer to the *LT2ESWTR Toolbox Guidance Manual*
44 (USEPA 2003a) for detailed requirements for receiving credit.

Removes AOC After Ozone

Ozonation often results in organic matter becoming AOC, which serves as a food source for microbes. This can cause difficulties with compliance with the Total Coliform Rule (TCR) and can lead to nitrification problems. GAC, acting as an adsorbent, can remove some AOC before it enters the distribution system.

> **Using GAC in a second filter can:**
>
> - **lower DBP precursors and other organics**
> - **help meet the Stage 2 DBPR requirements**
> - **achieve *Cryptosporidium* removal credit for the LT2ESWTR**

Additionally, systems can take advantage of the high surface area per mass ratio of GAC and the fact that it adsorbs organics to operate the GAC filter in biologically active mode. By not having a disinfectant residual in the water passing through the filter and allowing biological growth, the system can achieve high removals of AOC. Using biologically active GAC filters after ozonation can reduce biological growth in the distribution system and lower DBPs. See Section 5.2 for further details on the use of biological filtration with ozone.

4.1.2 Potential Operational and Simultaneous Compliance Issues Associated with Using GAC

Potential issues associated with GAC use include:

- **Can limit the ability to prechlorinate**

- **Previously adsorbed compounds can be released**

- **Bacteria can be released**

- **Carbon fines released from GAC filters can foul downstream processes**

- **Chlorate can be formed when GAC comes in contact with chlorine dioxide**

- **Ammonia added before a GAC filter has been found to increase nitrification in the distribution system**

This section briefly describes each of these issues and provides some suggestions for addressing them.

Limits Ability to Prechlorinate

Most disinfectants react quickly when they come into contact with GAC. This leads to a rapid loss of disinfectant residual, and in the case of chlorine, can lead to a faster depletion of the GAC.

Recommendations for Addressing this Issue

Systems should not use GAC filters at the same time as achieving CT for purposes of meeting disinfection requirements. Disinfectants should be added after the GAC filter. If the disinfectant addition points are moved, an evaluation of the CT throughout the plant must be made and any effects of moving the disinfection point, such as changes in coagulation and precipitation, pre-oxidation of contaminants, and growth of algae must be evaluated. If pre-oxidation is needed in treatment before GAC, alternative oxidants (e.g., potassium permanganate) or lower chlorine doses should be used so as not to carry a residual onto the GAC.

Release of Adsorbed Compounds

Organic materials adsorbed onto GAC will generally remain on the GAC until it is regenerated. But if a stronger adsorbing compound passes through the GAC when the GAC is relatively saturated, and the GAC does not have a significant number of free adsorption sites, weaker binding compounds can be expelled. It is possible for the concentration of these expelled compounds to be higher than the original concentration. This phenomenon is referred to as chromatographic peaking. Strongly adsorbing compounds that can have this effect include hydroxide used to adjust pH, or chloride as a byproduct of chlorination.

Recommendations for Addressing this Issue

To avoid chromatographic peaking and the desorption of contaminants from the GAC, pH adjustment should be made after the GAC filter. Chlorine should also generally be added after the GAC filter, both to avoid chromatographic peaking and to lower DBP formation. Any other sudden changes in water chemistry entering the GAC contactor should be avoided as well. If sudden swings in water chemistry are unavoidable, then GAC regeneration frequency should be increased and the filter effluent should be monitored carefully to prevent breakthrough of any contaminants.

Release of Bacteria

Heterotrophic bacteria growth occurs in GAC filters. Studies have found that the average number of bacteria in the effluent of GAC systems can be significantly higher than influent levels (Parson et al. 1980, Klotz et al. 1976). This may present problems with biofilms or

1 opportunistic pathogens for water systems with inadequate post-GAC disinfection. It can also
2 contribute to nitrification problems when ammonia is present naturally or through use of
3 chloramines.
4
5   Recommendations for Addressing this Issue
6
7   The amount of bacteria in the effluent of GAC systems can often be reduced by proper
8 backwashing and GAC regeneration frequencies. However, some bacteria are still likely to be
9 shed from GAC filters. Introducing a disinfectant residual in the filter itself is not recommended
10 because most disinfectants react with GAC, spending the GAC and not penetrating the full depth
11 of the bed. The best strategy to deal with bacteria shed from GAC filters is to add a disinfectant
12 after the GAC filter.
13
14 *Release of Carbon Fines*
15
16   Small particles of carbon are usually present in GAC filters when they are first installed.
17 These carbon fines appear gray or black and can cloud the water. If carbon fines from GAC
18 filters are released into the product water, they can interfere with downstream treatment
19 processes, particularly fouling of membrane filters and absorbing ultraviolet (UV) light in UV
20 disinfection units, and cause poorer performance of these subsequent treatment steps.
21
22   Recommendations for Addressing this Issue
23
24   GAC filters should be placed after membrane or UV disinfection processes to avoid
25 problems associated with the release of carbon fines. If this is not possible, proper backwashing
26 procedures, good maintenance of the filter underdrains, and more frequent cleaning of the UV
27 reactor or membrane unit can help to minimize the problem.
28
29 *Formation of Chlorate*
30
31   Chlorine dioxide, in addition to losing its residual, will form chlorate when it comes into
32 contact with GAC. Chlorate can further react to form chlorite, a DBP regulated by the Stage 1
33 D/DBPR.
34
35   Recommendations for Addressing this Issue
36
37   Chlorine dioxide should be added after the GAC filters to avoid the formation of chlorate.
38 If chlorine dioxide is used for pre-oxidation, it should be added far enough ahead of the GAC
39 filter that no residual enters the contactor. If the treatment sequence first has conventional
40 filtration and then the GAC filter, adding the chlorine dioxide prior to the first set of filters will
41 usually solve the problem.
42

1   *Nitrification with Chloramines*
2
3   Systems that add ammonia prior to a GAC contactor have been found to have more
4   frequent incidents of nitrification in the distribution system (Krasner et al. 2003). This may be
5   caused by the ammonia stimulating growth of nitrifying bacteria on the GAC media and seeding
6   the distribution system with these bacteria, though the research has not been conclusive.
7
8   Recommendations for Addressing this Issue
9
10   To reduce the potential for nitrification, systems using ammonia to form chloramines or
11 to raise pH should add the ammonia after the GAC filters.
12
13 **4.1.3   Recommendations for Gathering More Information**
14
15 *Read the Case Study*
16
17   For more information on simultaneous compliance issues associated with GAC and how
18 to address them, see ***Case Study #7 - Granular Activated Carbon for TOC removal*** starting on
19 page B-45 of Appendix B. This case study describes how a utility used GAC to address high
20 levels of atrazine in its source water and high TTHM levels in its finished water. The system
21 was able to reduce their atrazine levels 30 to 60 percent and their UV_{254} levels 20 percent six
22 months after installing the GAC cap. The greatest operational issue faced by the system was a
23 build up of inorganic precipitates on the GAC filter, and occasional taste and odor episodes.
24
25 *See Additional References*
26
27   Readers can turn to Chapter 7 for more references on this topic. Section 7.1.1 includes
28 general references on water treatment, Section 7.1.2 contains references on controlling DBP
29 formation, and section 7.1.9 contains references on GAC use.
30
31 *Consider Additional Monitoring*
32
33   The following are some suggestions for additional monitoring that may benefit water
34 systems implementing GAC. Note that the purpose of these monitoring suggestions is
35 specifically to address and prevent potential simultaneous compliance issues. Water system
36 managers should discuss process control monitoring with the GAC manufacturer or their
37 engineer.
38
39   ✓   Periodic monitoring of volatile organic chemicals (VOCs) and synthetic organic
40   chemicals (SOCs), as appropriate, in water leaving the GAC unit to detect
41   breakthrough and desorption of contaminants.
42

1   ✓ Turbidity or particle count measurements of the GAC effluent, especially when new
2   or re-activated carbon is first being used.
3
4   ✓ Heterotrophic plant counts (HPC) in water leaving the GAC units to watch for an
5   increase in bacteria numbers.
6
7 *Consider Other Tools*
8
9   In addition to water quality monitoring, there are additional tools available in Chapter 6
10 to help systems evaluate and improve their current water system in relation to the compliance
11 issues they may face when modifying their treatment practices. Examples of tools that can be
12 used when GAC is used for Stage 2 DBPR compliance include:
13
14   • The AwwaRF report "Prediction of GAC Performance Using Rapid-Small Scale
15   Column Tests" (Crittenden 1989) that describes the use of RSSCT techniques to
16   predict full-scale GAC's useful lifetime when it is used to remove dissolved organic
17   matter from a drinking water source. This report also demonstrates how to use pilot-
18   scale testing data to further refine the RSSCT prediction
19
20   • The "Handbook of Public Water Systems" (HDR Engineering, Inc. 2001) which
21   provides detailed engineering design aspects of various drinking water treatment
22   processes including granular activated carbon
23
24   • The second version of "Water Treatment Plant Model" (U.S. EPA 2001h) developed
25   by USEPA in 2001 that assists utilities with implementing various treatment changes,
26   including GAC addition, while maintaining adequate disinfection and meeting the
27   requirements of Stage 2 DBPR
28
29   • Various cost estimation models that can be used to estimate the cost of constructing
30   and operating a new GAC facility.
31
32 Readers are encouraged to read through Chapter 6 before making any final compliance decisions.
33

1   **4.2   Microfiltration/Ultrafiltration**
2
3   Microfiltration/Ultrafiltration (MF/UF) is a low-pressure membrane technology. The
4   membranes remove particulate matter larger than the membrane pore size. MF membranes
5   generally operate at slightly lower pressure and have larger pore sizes than UF membranes. In
6   some cases, MF/UF membranes will be used together, with the MF membranes acting as a pre-
8   filter for the UF membranes. MF/UF

10 units are often supplied on skid
12 mounted assemblies that can easily
14 be installed and have high degrees of
16 automation.
18

> An advantage of MF/UF is that it can achieve high removal rates of bacteria, *Giardia* and *Cryptosporidium*. This allows a system to lower its disinfectant dose and possibly reduce its finished water DBP concentrations.

20 **4.2.1   Advantages of MF/UF**
22
23   The advantages of MF/UF include:
24
25
26   •   **Removes bacteria and protozoa**
27
28   •   **Can lower DBPs by using lower disinfectant doses**
29
30   •   **Removes arsenic**
32
33 *Bacteria and Protozoa Removal*
34
35   Membrane processes remove all particles larger than the pore size of the membrane,
36 provided the membrane integrity is not compromised. Bacteria, *Cryptosporidium* oocysts, and
37 *Giardia* cysts can all be reliably removed by MF/UF. Although MF membranes do not generally
38 remove viruses, some UF membranes can remove viruses. MF/UF units that are challenge-tested
39 before installation and undergo daily membrane integrity tests qualify for 2.5 log additional
40 *Cryptosporidium* removal credit above that of conventional treatment under the LT2ESWTR.
41 See the *LT2ESWTR Toolbox Guidance Manual* (USEPA 2003a) for more information. Systems
42 should also consult with their state to determine applicable credits and requirements.
43
44   If surface water systems use MF/UF instead of chemical disinfection to get
45 inactivation/removal credit, they must add chlorine, chloramines, or chlorine dioxide to maintain
46 a disinfectant residual in the distribution system.
47
48 *DBP Reduction*
49
50   Because MF/UF can achieve high levels of microbial removal, systems installing MF/UF
51 can lower their disinfectant dose and still achieve the same level of microbial protection. The

1 lowered disinfectant dose may result in lower DBPs and aid in meeting Stage 2 DBPR
2 requirements.
3
4 **4.2.2   Potential Operational and Simultaneous Compliance Issues Associated with MF/UF**
5
6   Potential issues associated with MF/UF use include:
7
8
9   • **Can be fouled by organics and minerals**
10
11   • **Increased loss of process water**
12
13   • **Additional training required**
14
15
16   This section provides brief descriptions of these issues and suggestions for minimizing
17 their impacts.
18
19 *Membrane Fouling*
20
21   Membranes can be fouled by organic matter, iron, manganese, and carbonate deposits.
22 Sources of these fouling compounds include source water and treatment chemicals. Ground
23 water systems that do not treat their water before it passes through the MF/UF unit may have
24 particular problems with iron, manganese, and other minerals. This is especially true if the
25 ground water is anoxic and is exposed to the atmosphere during pumping or an aeration process,
26 resulting in dissolved minerals settling out.
27
28   <u>Recommendations for Addressing this Issue</u>
29
30   Systems with high TOC can reduce fouling by placing the MF/UF after existing
31 sedimentation and/or filtration processes. If TOC is high even after filtration or if a conventional
32 filter is not present, TOC can be lowered by adding other pretreatment techniques. Pretreatment
33 to lower TOC levels includes: pre-sedimentation, enhanced coagulation and, less often, GAC
34 filtration. TOC removal can often be accomplished by good coagulation before the membranes.
35 If iron based coagulants are used, jar testing should be carried out to ensure optimal dosing and
37 settling, because iron based
39 coagulants can foul some
41 membranes. GAC filtration removes
43 much of the organic matter, although
45 not all organic compounds are
47 adsorbed easily. A cartridge filter
49 may need to be installed before the
51 MF/UF unit, however, to prevent
53 carbon fines from entering the

If TOC is high after filtration, it can be lowered through other pretreatment techniques, including:
• **pre-sedimentation**
• **enhanced coagulation**
• **GAC filtration (less often).**

1   membrane unit.
2

3   Systems that aerate their ground water to oxidize iron, manganese or other compounds
4   should remove any precipitated minerals before the water reaches the MF/UF unit to prevent
5   fouling. The manufacturer of the MF/UF unit and other utilities with experience using the same
6   units should be consulted before a system makes any changes to the chemistry of the treated
7   water, since many treatment chemicals can also foul membranes.
8

9   Regardless of the pretreatment involved and the quality of the water, membranes will
10   eventually foul and will need to be cleaned. Cleaning the membranes will improve performance
11   and prolong membrane life. The appropriate length between cleanings can be determined by
12   monitoring the long-term decrease in productivity and backwash efficiency.
13

14   *Loss of Process Water*
15

16   Membrane processes produce a reject stream as well as backwash water. Therefore, the
17   amount of wastewater that has to be handled can be higher than that produced during
18   conventional filtration. Although improvements have been made in efficiency, some water
19   systems lose as much as 15 percent of the process water as a waste stream. Other membrane
20   projects have been bid with approximately 92 percent recovery in summer and 90 percent
21   recovery in winter (Sarah Clark, personal communication). In a recent survey of MF/UF
22   systems, however, the median value for feed water recovery was 95 percent (Adham et al.,
23   2005).
24

25   <u>Recommendations for Addressing this Issue</u>
26

27   To handle the higher quantities of process water produced by MF/UF units, systems may
28   need to increase the capacity of their wastewater storage and residuals processing facilities. This
29   is especially true of systems that recycle their reject water.
30

31   To minimize the lost water, systems may also be able to recycle some of the reject stream
32   if the membranes are added onto a conventional treatment train. In this case, the recycle must be
33   sent to the head of the plant according to the Filter Backwash Recycling Rule (FBRR). The
34   effect of additional particle loading should be taken into account when determining coagulant
35   dosing and filter loading rates.
36

37   *Additional Training Required*
38

39   MF/UF membranes are significantly different to operate than other water treatment units.
40   The control parameters are different and many new parameters must be monitored to prove
41   regulatory compliance.
42

1   Recommendations for Addressing this Issue
2
3   Systems should consult with their state to determine what parameters will need to be
4   monitored for approval and regulatory compliance. Systems should also work with the state and
5   the vendor to provide adequate training for operators.
6
7   **4.2.3   Recommendations for Gathering More Information**
8
9   *See Additional References*
10
11   Readers can turn to chapter 7 for further references on this topic. Section 7.1.1 contains
12   general references on water treatment, and section 7.1.10 contains references on membranes,
13   including MF/UF.
14
15   *Consider Additional Monitoring*
16
17   The following are some suggestions for additional monitoring that may benefit water
18   systems implementing MF/UF. Note that the purpose of these monitoring suggestions is
19   specifically to address and prevent potential simultaneous compliance issues. Water system
20   managers should discuss process control monitoring with the MF/UF manufacturer and other
21   experienced utilities.
22
23   ✓ Periodic monitoring of iron, manganese, and other minerals in the water entering the
24   MF/UF unit to detect an increase in minerals that may need to be addressed by pre-
25   treatment.
26
27   ✓ Particle counting to indirectly monitor membrane integrity and determine if a direct
28   integrity test should be conducted.
29
30   ✓ Total organic carbon (TOC) in the membrane unit's influent and effluent to track
31   removal performance.
32
33   ✓ Heterotrophic plate counts (HPC) in the membrane unit's effluent if membrane
34   integrity is lost.
35
36   ✓ Membrane autopsies on any failed membranes to determine the cause of failure and
37   determine possible corrective actions.
38

1 *Consider Other Tools*
2
3   In addition to water quality monitoring, there are additional tools available in Chapter 6
4 to help systems evaluate and improve their current water system in relation to the compliance
5 issues they may face when modifying their treatment operations. Examples of tools that can be
6 used when MF/UF membranes are used for LT2ESWTR and Stage 2 DBPR compliance include:
7
8   • The "Membrane Filtration Guidance Manual" published by USEPA in 2005 provides
9   general guidelines for membrane pilot testing;
10   • The AwwaRF report "Integrated Membrane Systems" (Schippers et al. 2004) that
11   provides guidance on the selection, design, and operating an integrated membrane
12   system that can function as a synergistic system for removing microbiological
13   contaminants and DBP precursors;
14   • The AwwaRF report "Integrating Membrane Treatment in Large Water Utilities"
15   (Brown and Hugaboom 2004) that provides guidance to issues related to the
16   integration of low pressure membranes into larger water treatment facilities, including
17   membrane layout, piping, cost comparison, and operations and maintenance;
18   • The second version of "Water Treatment Plant Model" (U.S. EPA. 2001h) developed
19   by USEPA in 2001 that assists utilities with implementing various treatment changes
20   while maintaining adequate disinfection and meeting the requirements of Stage 2
21   DBPR; and
22   • Various cost estimation models that can be used to estimate the cost of constructing
23   and operating a new membrane facility.
24
25 Readers are encouraged to read through Chapter 6 before making any final compliance decisions.
26
27

4.3   Nanofiltration

Nanofiltration is a membrane process that physically removes contaminants from water that are larger than the pore size of the membranes. Nanofiltration uses pore sizes and operating pressures that fall between those of UF and reverse osmosis.

> **Nanofiltration's main advantage is that it can remove virtually all particulate matter as well as larger dissolved compounds, including some dissolved organic matter.**

Nanofiltration's main advantage over MF/UF is that it can remove virtually all particulate matter as well as larger dissolved compounds, including dissolved organic matter. In addition to meeting all removal requirements for pathogens, it leads to lower DBPs by removing DBP precursors. Its main disadvantages are that it can be fouled by organics or precipitated minerals, it can increase corrosiveness of the water, it has a large reject stream, and it requires additional training.

4.3.1   Advantages of Nanofiltration

Some advantages of nanofiltration include:

- **Significant removal of bacteria, protozoa, and viruses**

- **Can remove organics that act as DBP precursors**

- **Can remove arsenic**

Significant Removal of Bacteria, Protozoa, and Viruses

Nanofiltration has small pore sizes that exclude essentially all particulate matter, as long as the membrane is intact. Therefore, nanofiltration units that are capable of being integrity tested may receive credit for *Cryptosporidium* removal under LT2ESWTR. With state approval, if nanofiltration is used to satisfy pathogen removal/inactivation requirements instead of a combination of filtration and disinfectant, the system must still add chlorine, chloramines, or chlorine dioxide for residual disinfection in the distribution system.

Removes DBP Precursors

Nanofiltration can remove dissolved organic compounds that serve as DBP precursors. When little or no bromide ion was present in the source water, nanofiltration membranes with molecular weight cutoffs (MWCOs) of 400 to 800 daltons were shown to effectively control DBP formation (Laine et al. 1993). Nanofiltration with the same pore size produced higher bromoform concentrations when bromide was present, although total THMs decreased.

Membranes with smaller pore sizes controlled bromoform formation better but required
pretreatment to avoid membrane fouling.

DBP formation may be lowered even further if the state allows the system to reduce its
disinfectant dose and the amount of primary disinfection because of the high microbial removal
rate of the nanofiltration units. When this is the case, nanofiltration can accomplish both high
pathogen removal and low DBP formation.

4.3.2   Potential Operational and Simultaneous Compliance Issues Associated with Nanofiltration

Potential issues associated with nanofiltration include:

- **Can be fouled by organics and precipitated minerals**

- **Can increase corrosiveness of water**

- **Issues with reject stream**

- **Additional training required**

This section briefly describes these issues and provides suggestions for addressing their
impacts.

Membrane Fouling

Organics and precipitating minerals can foul nanofiltration membranes and cause them to
operate inefficiently, shortening their useful life. Fouling also increases operating pressures and
causes more frequent backwashing, which raises operating expenses. Fouling agents can come
from the source water or be introduced as part of the treatment process. Ground waters that are
not filtered before the water passes through the membranes may have more difficulties with
fouling.

Recommendations for Addressing this Issue

If nanofiltration membranes are being used in conjunction with a conventional filtration
plant, the membranes should be placed after the filters to allow for the maximum removal of
fouling compounds before water passes through the membranes. Treatment processes that can
change the chemistry of the water should be located downstream of the nanofiltration unit if
possible. These include aeration, pH adjustment, and disinfectants. Systems should bear in
mind, however, that nanofiltration generally works better at acid pH.

1   If the treatment train in place is not sufficient to reduce fouling compounds, some sort of
2 pretreatment will be required. The simplest pretreatment is adding a cartridge filter before the
3 membranes. If the water being treated is anoxic ground water, aeration may be considered to
4 oxidize and precipitate any minerals before the cartridge filter. Other options for pretreatment
5 include enhanced coagulation and pre-sedimentation. If enhanced coagulation is used, jar testing
6 should be conducted to optimize the dose to ensure that unflocculated coagulant does not enter
7 the membrane unit.
8
9   Regardless of the pretreatment involved and the quality of the water, membranes will
11 eventually foul. Cleaning the
13 membranes is necessary for
15 improving performance and
17 prolonging membrane life. The
19 appropriate length between
21 cleanings can be determined by
23 monitoring the long-term decrease
25 in productivity and back wash
27 efficiency.

> **If coagulants or disinfectants must be added prior to membranes, the system should consult the membrane manufacturer and other experienced utilities to determine if the chemicals will cause fouling or otherwise damage the membranes.**

28
29 *Increase Corrosiveness*
30
31   Nanofiltration can soften water by removing minerals such as calcium and magnesium. It
32 can also result in a lowering of the pH of the water. The less alkaline, lower pH water will be
33 more corrosive to distribution system piping and other process equipment, while not providing a
34 passivating layer as harder water can. The lower pH can also shift the carbonate equilibrium to
35 produce carbon dioxide. In groundwaters, hydrogen sulfide can also pass through the
36 membranes. All these factors combine to increase the corrosiveness of the water.
37
38   Increased corrosiveness can cause problems with Lead and Copper Rule (LCR)
39 compliance. Depending on the magnitude of the pH drop, it may also affect the disinfection
40 efficiency of the secondary disinfectant as well. See Section 3.4 for more discussion of
41 disadvantages associated with lowering water pH. It is also possible that the removal or minerals
42 such as calcium can be so significant as to cause the water to taste significantly different to
43 customers, possibly generating customer complaints.
44
45   <u>Recommendations for Addressing this Issue</u>
46
47   The simplest way to avoid problems associated with a low pH is to adjust the pH after the
48 membranes. The fittings for the membrane unit, as well as any equipment between the
49 nanofiltration unit and the point where the pH is readjusted, should be made of materials that can
50 resist the lower pH of the water. Water systems should also adjust the alkalinity after
51 nanofiltration to prevent changes in pH in the distribution system that can enhance corrosion.

1 Passive treatment technologies, such as neutralizing filters or limestone contactors, are one way
2 to achieve a good pH and carbonate balance in membrane-treated waters.
3
4   Aeration may help to remove any sulfide or carbon dioxide accumulated as well as raise
5 oxygen levels to oxidize the sulfide to sulfate. Adding a disinfectant after the membranes can
6 also aid in oxidizing sulfide.
7
8   Another approach some systems have taken is to only pass part of the influent stream
9 through the NF unit and blend that NF product with water that has not received NF treatment.
10 However, this negates many of the microbial benefits of NF and would require an alternative
11 microbial treatment on the stream not treated by NF.
12
13 *Issues with Reject Stream*
14
15   Membrane processes produce a reject stream as well as backwash water. Therefore, the
16 amount of wastewater that has to be handled can be significantly higher than that produced
17 during conventional filtration. Although improvements have been made in efficiency, losing 10
18 to 20 percent of the process water as a waste stream is not unusual. The amount of process water
19 lost can be reduced by a second membrane unit in series with the first unit.
20
21   Due to the small pore size associated with nanofiltration, other feed water constituents
22 will also be removed. As a result, divalent salts, some metals, and some soluble organic carbon
23 may be concentrated in the waste stream. This may increase the cost associated with disposing
24 of the waste stream compared to disposal costs associated with MF, UF, and conventional
25 treatment processes. If regulatory limits or plant locations prohibit sending the waste stream to a
26 receiving body or wastewater treatment plant, costs for waste handling and disposal can be
27 substantial.
28
29   Recommendations for Addressing this Issue
30
31   To handle the higher quantities of waste water produced by nanofiltration units without
32 causing upset to the system, utilities may need to increase the capacity of their wastewater
33 storage and residuals processing facilities. This is especially true of systems that recycle their
34 reject water. If water is recycled, the Filter Backwash Recycling Rule (FBRR) requires that it be
35 recycled to the head of the plant.
36
37   Water systems using nanofiltration will most likely need to increase the amount of water
38 they withdraw from their source to account for their process water losses. This could be an issue
39 in arid regions where water is scarce and water restrictions are in place.
40
41   Disposal of the reject stream is easiest if located near an ocean, as the brine can easily be
42 disposed of there. Otherwise systems will need to discuss the possibility of disposing of the

1 brine to the sanitary sewer which may have limits on brine or on certain metals and may involve
2 additional charges.
3
4 *Additional Training Required*
5
6   NF membranes are significantly different to operate than other water treatment units.
7 The control parameters are different and many new parameters must be monitored to prove
8 regulatory compliance.
9
10   Recommendations for Addressing this Issue
11
12   Systems should consult with their state to determine what parameters will need to be
13 monitored for approval and regulatory compliance. Systems should also work with the state and
14 the vendor to provide adequate training for operators.
15
16 **4.3.3   Recommendations for Gathering More Information**
17
18 *Read the Case Study*
19
20   For more information on simultaneous compliance issues associated with nanofiltration
21 and how to address them, see ***Case Study #8 - Nanofiltration Membrane Technology for TOC***
22 ***Removal*** starting on page B-49 of Appendix B. This case study describes the challenges faced
23 by one PWS switching to nanofiltration in response to growing demands for water and the
24 implementation of new drinking water standards. Specifically, the NF plant would facilitate the
25 removal of hardness, color, TOC, and its related chlorinated DBPs. The greatest operational
26 issue involved numerous leaks in the acid feed system, and sagging in the micron cartridge filter
27 housings and the string wound filter.
28
29 *See Additional References*
30
31   Readers can turn to chapter 7 for further references on this topic. Section 7.1.1 contains
32 general references on water treatment, and section 7.1.10 contains references on membranes,
33 including NF.
34
35 *Consider Additional Monitoring*
36
37   The following are some suggestions for additional monitoring that may benefit water
38 systems implementing nanofiltration. Note that the purpose of these monitoring suggestions is
39 specifically to address and prevent potential simultaneous compliance issues. Water system
40 managers should discuss process control monitoring with the manufacturer of their nanofiltration
41 units or their engineer.
42

1   ✓ The pH of water leaving the nanofiltration unit should be monitored to ensure that 1)
2   CT is being calculated accurately; and 2) chemical dosages for corrosion control are
3   correct.
4
5   ✓ Hardness and alkalinity of water leaving the nanofiltration unit should be measured to
6   ensure that chemical dosages for corrosion control are correct.
7
8   ✓ TOC in the NF influent and effluent should be monitored to measure removal
9   effectiveness.
10
11   ✓ Particle counting to indirectly monitor membrane integrity and determine if a direct
12   integrity test should be conducted.
13
14   ✓ HPC should be measured in the NF effluent to identify breakthrough.
15
16   ✓ Membrane autopsies on any failed membranes to determine the cause of failure and
17   determine possible corrective actions.
18
19   ✓ Taste and odor quality should be measured to ensure customer acceptance.
20
21   *Consider Other Tools*
22
23   In addition to water quality monitoring, there are additional tools available in Chapter 6
24   to help systems evaluate and improve their current water system in relation to the compliance
25   issues they may face when modifying their treatment operations. Examples of tools that can be
26   used when nanofiltration is used for Stage 2 DBPR compliance include:
27
28   • The AwwaRF report "Integrated Membrane Systems" (Schippers et al. 2004) that
29   provides guidance on the selection, design, and operation of an integrated membrane
30   system that can function as a synergistic system for removing microbiological
31   contaminants and DBP precursors
32
33   • The AwwaRF report "Integrating Membrane Treatment in Large Water Utilities"
34   (Brown and Hugaboom 2004) that provides guidance on issues related to the
35   integration of low pressure membranes into larger water treatment facilities, including
36   membrane layout, piping, cost comparison, and operations and maintenance
37
38   • The AwwaRF report "NOM Rejection by, and Fouling of, NF and UF Membranes"
39   (Amy et al. 2001) that provides information on the selection of appropriate
40   nanofiltration membranes to achieve high NOM rejection, and also presents
41   information on how water quality (such as the presence of calcium and pH) and
42   operational condition might affect NOM rejection by NF membranes

1
2   • The second version of "Water Treatment Plant Model" (U.S. EPA. 2001h) developed
3   by USEPA in 2001 that assists utilities to implement various treatment changes while
4   maintaining adequate disinfection and meeting the requirements of Stage 2 DBPR
5
6   • Various cost estimation models, such as WTCost©, 2003, that can be used to estimate
7   the cost of implementing a new membrane facility (see Section 6.3.7).
8
9   Readers are encouraged to read through Chapter 6 before making any final compliance decisions.
10
11

1 **4.4   Other Microbial Removal Technologies**
2
3   Other microbial removal technologies can be used to meet LT2ESWTR requirements.
4   All of the technologies listed below use some type of filtration media to remove
5   *Cryptosporidium* oocysts and other microbes from drinking water. *The LT2ESWTR Toolbox*
6   *Guidance Manual* (USEPA 2003a) provides information on the requirements for receiving
7   *Cryptosporidium* oocyst removal credits using these technologies. The state should also be
8   consulted on the requirements for obtaining pathogen removal credit for these technologies.
9   Although these technologies are not expected to present significant compliance problems with
10 other drinking water regulations if implemented properly, there are operational issues that
11 utilities should consider if they use these options. These technologies are:
12
14   Bank Filtration
16   Bank filtration uses
18   vertical or horizontal wells
20   drilled near a riverbank.
22   The riverbed and material
24   between the well and the
26   riverbank act as the
28   filtration media.

> **The *LT2ESWTR Toolbox Guidance Manual* provides more information on the advantages and disadvantages of different *Cryptosporidium* oocyst removal technologies.**

29
30   Improved Filter Performance
31   Improved filter performance results from optimizing existing filtration to achieve
32   consistently low filter effluent turbidity. In order to meet the lower finished water
33   turbidity requirements, systems need a high level of process control from the source
34   water intake to the filters. The *Guidance Manual for Compliance with the IESWTR:*
35   *Turbidity Provisions* (USEPA 1999d) discusses many design and operational aspects
36   water systems should consider for achieving low effluent turbidity.
37
38
39   Bag Filtration
40   Bag filtration is a pressure driven filtration process using a fabric filter media. Flow is
41   from inside the vessel to outside the vessel.
42
43   Cartridge Filtration
44   Cartridge filters are pressure driven filtration devices that have rigid or semi-rigid filter
45   media housed in pressure vessels. Water flows from outside the cartridge filter's vessel to
46   the inside.
47

1   Second Stage Filtration
2   Second stage filtration involves placing a second set of granular media filters in series
3   with an existing set of filters. The media can be rapid sand filters, slow sand filters, or
4   GAC filters.
5
6   Slow Sand Filtration
7   Slow sand filtration uses sand as a filtration media and gravity as the driver at relatively
8   low loading rates.
9
10   Diatomaceous Earth Filtration
11   Diatomaceous earth (DE) filtration, often referred to as "pre-coat" filtration, uses a layer
12   of diatomaceous earth placed on a permeable cover or porous filter septum to filter water.
13   DE filters are operated as either pressure filters or vacuum filters.
14
15   This section briefly describes issues associated with the use of these technologies,
16 provides suggestions for addressing those issues, and recommends additional monitoring that can
17 be conducted.
18
19 **4.4.1   Advantages**
20
21   There are several advantages to these microbial removal technologies. The following
22 paragraphs list these advantages and briefly discuss which of these technologies provide each
23 advantage.
24
25
26   • **Ease of use (bag filtration, cartridge filtration bank filtration)**
27
28   • **Removal of *Cryptosporidium* and other pathogens (all technologies listed)**
29
30   • **Removal of other contaminants/ DBP precursors (bank filtration, second stage**
31   **filtration, slow sand filtration)**
32
33   Most operators are familiar with filtration. Second stage filtration, DE, and slow sand
34 filtration can all be easily implemented by any system familiar with conventional filtration.
35 Cartridge and bag filters are even easier to use as the only routine maintenance required is
36 replacing the cartridge or bag when a pre-set trigger is reached, either a pressure drop or a given
37 time.
38
39   All of these technologies will remove matter that is larger than the filter's effective pore
40 size. Therefore, in addition to *Giardia* cysts and *Cryptosporidium* oocysts, they will remove
41 some other microbial pathogens as well.
42

1   Some of these technologies can also be effective in removing DBP precursors. Slow
2   sand filtration can remove some DBP precursors, especially if operated in biologically active
3   mode. Second stage filtration can offer additional DBP precursor removal, especially when GAC
4   is used as the second filter media. Bank filtration often provides additional DBP removal
5   through biological activity in the riverbank (Weiss et al. 2003).
6
7   **4.4.2   Potential Operational and Simultaneous Compliance Issues**
8
9   The disadvantages of these microbial removal technologies include:
10
11
12   • **Hydraulic problems or scouring (all technologies listed)**
13
14   • **Clogging (cartridge filters, bank filtration)**
15
16   • **Increased residuals/ backwash (second stage filtration)**
17
18   • **Iron/manganese problems (bank filtration)**
19
20   • **Filter fouling (bag filters, cartridge filters)**
21
22   With careful planning, many of the disadvantages of these technologies can be overcome.
23   The following paragraphs briefly describe steps that can be taken to mitigate these
24   disadvantages.
25
26   *Hydraulic Problems or Scouring*
27
28   All of these technologies can add significant hydraulic head to a plant's hydraulic profile.
29   Changes in head, especially when filters are restarted, can disturb the filter and cause poor
30   performance.
31
32   Bank filtration can experience riverbank scouring during periods of high flow. The
33   riverbank scour can remove much of the finer grained sediment responsible for a large portion of
34   the removal associated with this filtration method.
35
36   Recommendations for Addressing this Issue
37
38   Hydraulic loss due to additional filtration can often be overcome by conducting a
39   hydraulic profile of the plant. Pumps can be installed to add additional head. The pumps should
40   be installed and operated in such a way as to not cause hydraulic disturbances to surrounding
41   processes, such as flocculation. Installing additional storage upstream of filtration is also a way

1 to smooth out hydraulic disturbances before they upset the filtration. Filtering to waste can
2 eliminate some of the problems associated with filter start-up.
3
4 *Clogging*
5
6 Bank filtration can also be subject to clogging by biomass growth in the pores or settling
7 of finer grained material in the pores. Although this may increase removal efficiency of
8 contaminants, it will increase pumping costs and drop yield. If too much coagulant is used
9 before cartridge filters, they can also clog, necessitating more frequent replacement and higher
10 costs.
11
12 Recommendations for Addressing this Issue
13
14 Some types of clogging in bank filtration can be avoided by proper siting of the wells.
15 Changes in chemistry in the aquifer that could precipitate minerals and areas of high
16 sedimentation should be avoided. Otherwise, some clogging is inevitable and even necessary.
17 Systems may have to account for this by designing for higher pumping rates than necessary or
18 installing multiple wells.
19
20 *Increased Residuals or Backwashing*
21
22 Many of these technologies can create disposal problems. Cartridge and bag filters have
23 to be disposed of periodically. Second stage filtration will generate additional backwash water
24 and residuals that will need to be disposed. Systems considering replacing their filter bed media
25 as part of an effort to improve filter performance should consider whether there will be
26 challenges associated with the disposal of old media that may contain high concentrations of
27 metals or other contaminants.
28
29 If significant amounts of additional backwash and residuals are generated, a system may
30 need to change its residuals disposal procedures. This may include treating backwash water
31 through the addition of coagulant, or adding new sludge dewatering technologies or other
32 residuals handling equipment.
33
34 Recommendations for Addressing this Issue
35
36 To handle the higher quantities of process water produced by backwashing filter units,
37 systems may need to increase the capacity of their wastewater storage and residuals processing
38 facilities. This is especially true of systems that recycle their reject water. Manufacturers can
39 also be consulted for disposal recommendations for bag and cartridge membranes.
40

Iron and Manganese Problems

Bank filtration can result in elevated levels of iron and manganese if the portion of the aquifer the wells draw from is anoxic. This will allow reduced manganese and iron to dissolve and enter the water.

Recommendations for Addressing this Issue

If bank filtration is carried out through an anoxic zone, aeration may need to be added to oxidize dissolved iron, manganese, and any other reduced chemical species that could cause operational or aesthetic problems.

Filter Fouling

Cartridge and bag filters can be fouled by biofilm if there is insufficient disinfectant residual present to control the growth. This can increase the pressure loss across the filter and shorten filter life.

Recommendations for Addressing this Issue

Adding disinfectant before the filters can prevent biofilm growth from clogging bag and cartridge filters. Systems should evaluate the potential for DBP formation before taking this step. Systems should also confirm that the filter media is compatible with the disinfectant.

4.4.3   Recommendations for Gathering More Information

See Additional References

Readers can turn to chapter 7 for additional references on this topic. Section 7.1.1 includes general references on water treatment, including filtration, Section 7.1.8 includes references on enhanced coagulation and softening, and Section 7.1.11 includes references on riverbank filtration.

Consider Additional Monitoring

Monitoring is important for determining the performance of these technologies. It can provide a good indication of performance and help make operating determinations such as when to backwash or replace filters.

✓ Turbidity is used to determine filter performance as well as warn that a filter needs to be backwashed. Monitoring of individual and combined filter effluents is required

1   for conventional filters. Even if the filter is installed as a second filter or in series
2   with another treatment technology, turbidity monitoring should be conducted.
3
4   ✓ Particle counters can also provide useful information, and can frequently determine
5   breakthrough before turbidity measurements can.
6
7   ✓ Flow measurements help to spot potential hydraulic upset and adjust loading rates
8   appropriately.
9
10   ✓ Pressure measurements are used to indicate how frequently a system needs to
11   backwash or whether filter media needs to be replaced.
12
13   ✓ Streaming current detectors can be used to detect the charge on particles and optimize
14   coagulant dose.
15
16   *Consider Other Tools*
17
18   In addition to water quality monitoring, there are additional tools available in Chapter 6
19   to help systems evaluate and improve their current water system in relation to the compliance
20   issues they may face when modifying their treatment operations. Examples of tools that can be
21   used when implementing the other microbial removal technologies described in this section
22   include:
23
24   ◆ The AwwaRF report "Evaluation of Riverbank Filtration as a Drinking Water
25   Treatment Process" (Wang et al. 2002) that provides a general guideline for the
26   design and operation of a riverbank system that can be used for the removal of DBP
27   precursors and microbial contaminants
28
29   • The second version of "Water Treatment Plant Model" (U.S. EPA 2001h) developed
30   by USEPA in 2001 that assists utilities with implementing various treatment changes,
31   including GAC addition, while maintaining adequate disinfection and meeting the
32   requirements of Stage 2 DBPR
33
34   • Various cost estimation models that can be used to estimate the costs of designing,
35   constructing, and operating one of the technologies described above.
36
37   Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

1   This page intentionally left blank.

.

5   Alternative Disinfection Strategies

1
2   In their efforts to comply with the Stage 2 DBPR and LT2ESWTR, public water systems
3 may consider switching to an alternative disinfectant for either primary or residual disinfection
4 (or both). This chapter describes potential simultaneous compliance issues associated with using
5 any of the following disinfectants:
6
7   ✓ chloramines
8   ✓ ozone
10   ✓ ultraviolet (UV)
12   ✓ chlorine dioxide
16
18 Suggestions are also provided for how systems can
20 mitigate simultaneous compliance and operational
22 issues that are identified.
24
26   In addition, Section 5.5 of this chapter
28 discusses different possible combinations of primary
30 and residual disinfectants, and simultaneous
32 compliance issues that may arise as a result of using
34 the disinfectants in combination.
36
37
38 **5.1   Chloramines**
39
40   Chloramines are formed when free chlorine reacts with ammonia. Chloramines may be
41 present as monochloramine, dichloramine, and/or trichloramine. Monochloramine is generally
42 considered the most desirable form for disinfection purposes. The chloramines compounds react
43 more slowly than free chlorine. As a result, they form fewer DBPs, and are more persistent in
44 the distribution system. Some studies have shown that chloramine compounds can penetrate
45 biofilms more effectively than free chlorine. Monochloramine is also a preferred residual for
46 odor quality of water, especially at residuals greater than 1 mg/L.
47
48   Because chloramine compounds are weaker disinfectants than free chlorine, they are not
49 usually used for primary disinfection but more frequently as a residual disinfectant in the
50 distribution system. If not properly controlled, chloramines can lead to nitrification episodes in
51 the distribution system and may cause taste and odor issues, loss of disinfectant residual, and
52 other problems.
.

> **ALTERNATIVE DISINFECTION STRATEGIES COVERED**
>
> - **Chloramine**
> - **Ozonation**
> - **Ultraviolet Light**
> - **Chlorine Dioxide**
> - **Primary and Residual Disinfectant Use**

.

1
2   ## 5.1.1   Advantages of Chloramines
3
4   The use of chloramination to comply with the Stage 2 DBPR presents numerous benefits
5   in terms of implementation and operation. Advantages include:
6
7
8   - **Lower DBP formation**
9
10 - **Chloramine residual concentrations are generally more persistent than free**
11   **chlorine residuals**
12
13 - **May help control of biofilm in the distribution system**
14
15
16 *Lower DBP Formation*
17
18   Chloramines react more slowly with organic matter than free chlorine. Total
19 trihalomethane (TTHM) and haloacetic acid (five) (HAA5) concentrations are usually lower than
20 when free chlorine is used for residual disinfection. Although detectable concentrations of
21 mono- and dichloroacetic acids can be produced, these are generally significantly lower than
22 corresponding concentrations produced by free chlorine. Replacing chlorine with chloramines as
23 a secondary disinfectant typically reduces TTHM levels 40 to 80 percent. Depending on the
24 system's water quality, the actual TTHM reduction can vary from 10 to 95 percent (Kirmeyer et
25 al. 2004a).
26
27   If chlorine is added to the water before ammonia, the byproducts associated with the use
28 of free chlorine can be formed, although additional formation will be significantly retarded once
29 the ammonia has been added. Because virus inactivation with free chlorine is more effective,
30 however, surface water systems frequently add chlorine early enough in the treatment train so
31 that CT requirements are achieved before the ammonia is added.
32
33 *More Persistent in the Distribution System*
34
35   Chloramines reacts more slowly than free chlorine. Chloramines also have a lower
36 oxidation-reduction potential than chlorine, so they are less likely to be consumed by reacting
37 with organics and reduced metals. They therefore last longer in the distribution system and are
38 generally more persistent than a free chlorine residual. The more persistent chloramine residual
39 means greater protection in the areas of the distribution system with long detention time and less
40 likelihood of violating the Surface Water Treatment Rule (SWTR) by failure to maintain a
41 disinfectant residual.
42

.

.

1   *Reduce Biofilm*
2
3   According to EPA (1992) and Jacangelo et al. (1987), chloramine compounds are better
4   able to penetrate the biofilm layer and inactivate attached organisms because they are more
5   limited than chlorine in the types of compounds with which they will react. LeChevallier et al.
6   (1988a, 1988b) found that chloramines were more effective at inactivating biofilms than free
7   chlorine. LeChevallier (1990) also found that, in iron pipes, 3 to 4 mg/L doses of free chlorine
8   did not control biofilm growth. Chloramines, however, did control biofilm growth at doses
9   starting at 2 mg/L. Recent research suggests that the factors affecting biofilm growth and
10   disinfection are complicated and may depend on many factors, thus varying between systems
11   (Ollos et al. 2003).
12
13   **5.1.2   Potential Operational and Simultaneous Compliance Issues Associated with**
14   **Chloramines**
15
16   Potential issues associated with the use of chloramines include:
17
18
19   • **Onset of nitrification in the distribution system**
20
21
22   • **Increased corrosion and metal release**
23
24   • **Taste and odor issues**
25
26   • **Issues for systems wanting to blend chloraminated and chlorinated waters**
27
28   • **Weaker disinfectant, generally not used as primary disinfectant**
29
30   • **Blending Issues - chloraminated and chlorinated waters**
31
32   • **Although ammonia feed operation is fairly straightforward, there are safety**
33   **concerns**
34
35   • **Ozone and granulated activated carbon (GAC) can lead to faster residual decay**
36
37   • **Issues for dialysis patients, fish owners, and industrial customers**
38
39
40   *Nitrification*
41
42   Biological nitrification is the
43   oxidation of ammonia to nitrite and then

```
┌─────────────────────────────────────────────┐
│ More Information on Nitrification             │
│ can be found at                               │
│ http://www.epa.gov/safewater/tcr/tcr.html     │
└─────────────────────────────────────────────┘
```

.

.

1   eventually to nitrate by bacteria and other organisms. Systems that carry an ammonia residual
2   along with the chloramines, and have warm temperatures, long distribution system residence
3   times, and low chloramine residuals can experience nitrification episodes (Kirmeyer et al.,
4   2004a). Nitrifying bacteria exhibit slow growth and are inhibited by sunlight. They have been
5   found in higher numbers in the sediment of distribution systems than in the biofilm (Wolfe et al.
6   1988, 1990). As part of the TCR review process, EPA has published a white paper on the issue
7   of nitrification. The paper can be found at: *http://www.epa.gov/safewater/tcr/tcr.html*.
8
9   Nitrification can have various adverse effects on water quality, including:
10
11   •   a loss of total chlorine and ammonia residuals (Cowman and Singer 1994)
12   •   consumption of dissolved oxygen
13   •   an increase in nitrite and nitrate levels
14   •   an increase in HPC
15   •   a decrease in pH
16   •   a decrease in ORP (relative to chlorinated water)
17
18   An increase in microbial activity can cause systems to violate the Total Coliform Rule (TCR)
19   and SWTR.
20
21   Research has shown that a chlorine demand of 5.0 mg/L is exerted by 1.0 mg/L of nitrite
22   (Cowman and Singer 1994). The nitrite rapidly reduces free chlorine, accelerates decomposition
23   of chloramines, and can interfere with the measurement of free chlorine (Skadsen 1993). If
24   nitrification episodes are allowed to continue, very low (or zero) total chlorine residual
25   concentrations may result.
26
27   As part of the TCR review process, EPA has published a white paper on the issue of
28   nitrification. The paper can be found at: *http://www.epa.gov/safewater/tcr/tcr.html*.
29
30   Several factors can contribute to nitrification, including, but not limited to:
31
32   •   low chlorine to ammonia ratio
33   •   long detention times, such as in storage tanks
34   •   high (25°C - 30°C) temperatures (Wolfe et al. 1988, 1990)
35   •   pH - Water systems operating with pH between approximately 7 and 8.5 have been
36   shown to be particularly vulnerable to nitrification.
37
38   Nitrifying bacteria are more resistant to disinfection by chloramines than by free chlorine
39   (Wolfe 1990). For this reason, many systems using chloramines as their residual disinfectant
40   will periodically switch to free chlorine to carry out a "chlorine burn." By changing over to free

.

.

1   chlorine for a few weeks or months, nitrifying bacteria numbers can often be significantly
2   reduced.
3
4   Recommendations for Addressing this Issue
5
6   Nitrification may be controlled by taking corrective action when chloramine residuals are
7   depleted in the distribution system. This can be done by monitoring the monochloramine
8   residual at strategic locations throughout the distribution system (White 1999). As stated earlier,
9   monitoring water, pH, nitrite, and temperature can also help determine when conditions are
10   favorable for nitrification. Alkalinity decreases without a loss in inorganic carbon concentration
11   has also been indicative of nitrification in some water systems. Decreases in pH alone may be
12   hard to detect in well-buffered waters.
13
14   Mechanisms for controlling the occurrence of coliform growth and nitrification include:
15
16   •   higher chloramine residuals,
17   •   higher chlorine: ammonia-nitrogen ratios,
18   •   periodic switching to free chlorine (particularly during warmer months),
19   •   operations to reduce water residence time, such as more frequent turnover in storage
20   reservoirs,
21   •   distribution system flushing (Kirmeyer et al., 2004a), and
22   •   optimization of corrosion control operation for high pH.
23
24   Systems should monitor source water for ammonia and take that into account when
25   calculating the necessary ammonia dose. The easiest way to reduce excess ammonia is to
26   increase the chlorine to ammonia ratio. Wolfe (1990) found that increasing the chlorine to
27   ammonia weight ratio from 3:1 to 5:1 reduced the free ammonia concentration from 0.2 mg/L to
28   nearly zero with a residual chloramine concentration of 1.5 mg/L.
29
30
31
32
33   The distribution system should be evaluated to identify the low-flow or dead-end
34   sections. Detention times in the system should be operationally minimized (Skadsen 1993).
35   Flushing dead ends can also decrease holding time and control nitrification.
36
37   Reducing the residence time in storage tanks can be an important factor in preventing
38   nitrification. Reductions in residence times can be achieved by structural changes to the
39   reservoir, such as changing the inlet/outlet structure, using recirculation pumps, and changing
40   system-pumping procedures.
41
42
43   *Increased Corrosion and Metal Release in the Distribution System*
44

.

.

1   Nitrification resulting from the use of chloramines can lower the alkalinity and the pH of
2   the water in the distribution system. The dissolved inorganic carbon level would be unaffected,
3   the alkalinity decrease being a function of the amount of pH drop observed. This can prove
4   detrimental for lead and copper control. Corrosion products and tubercles also interfere with the
5   disinfection of coliform and heterotrophic bacteria, which can lead to increased microbially-
6   induced corrosion.
7
8   Changing from free chlorine to chloramines in the distribution system could potentially
9   impact the stability of pipe scales, particularly redox-sensitive minerals such as those of lead,
10   copper, manganese, and iron. Changes in the solubility, permeability and/or stability of scales
11   could possibly result in the release of metals from pipe materials, increased oxidant demand or
12   desorption of materials which had adsorbed to or been incorporated in the scales.
13
14   Systems with lead service lines could possibly see changes in lead levels as a result of a
15   switch to chloramines. Pipe scale analysis has shown that, in some distribution systems where
16   free chlorine is used, the corrosion by-products on lead service lines contain significant amounts
17   of lead (IV) oxide compounds (Schock 2001; Schock, Wagner and Oliphant 1996; AWWARF
18   and DVGW-Technologiezentrum Wasser 1996; Lytle and Schock 2005; Schock and Giani 2004;
19   Schock et al. 2005). Lead (IV) oxide scales are highly oxidized and considered to be relatively
20   insoluble in water. If a water system switches from a strong oxidant (chlorine) to a weaker
21   oxidant (chloramines), the redox potential necessary to maintain Pb(IV) stability may no longer
22   remain. As a result, lead (IV) compounds may be reduced to more soluble lead (II) solids and a
23   subsequent increase in lead concentrations in water may be observed. This is the suspected
24   cause of the LCR action level exceedances experienced by Washington, D.C.'s Water and Sewer
25   Authority (DCWASA) beginning in 2002. DCWASA had made the conversion from free
26   chorine to chloramines in late 2000 with the goal of reducing TTHM and HAA5 levels in the
27   distribution system. The Washington, D.C. system does not contain any lead water mains;
28   however, more than 20 percent of its service lines are known to be made of lead. To address the
29   lead corrosion problem, the city accelerated its lead service line replacement program and began
30   orthophosphate treatment in August 2004. The treatment program appears to be successful in
31   reducing substantially elevated lead levels. LCR monitoring results for 2005 showed that the
32   calculated 90th percentile values were below the lead action level.
33
34   There have been some indications that chloramines can corrode brass. Edwards et al.
35   (2004) found accelerated brass corrosion in 7 of 8 brass samples tested, and a slight increase with
36   chloramines as opposed to free chlorine. Reiber et al. (1993) did not observe any additional
37   corrosion of brass in the presence of chloramines above what was seen with free chlorine.
38   Ammonia is known to be corrosive to brass and it is possible that excess ammonia and nitrate,
39   caused by nitrification can accelerate brass corrosion. Uchida and Okuwaki (1999) found lead
40   corrosion (lead is a component of brass) to be higher in the presence of ammonia and nitrate

.

.

1   together. Maas et al. (2005) found that fluoridation of water in combination with chloramines
2   can cause accelerated brass corrosion.
3
4   Chloramines have also been found to be corrosive to some elastomer materials.
5   Prolonged exposure of elastomer materials, such as those used in gaskets and valve seals, can
6   lead to cracking and loss of integrity (Reiber 1991). Although free chlorine can also cause
7   corrosion of these materials, chloramines show significantly higher corrosion rates.
8
9   A recent study (Bonds 2004) showed that, although there is significant corrosion of
10   vulcanized elastomers by chloramine compounds, components that have a low surface area to
11   volume ratio, such as gaskets, do not corrode significantly. One system in the study showed no
12   degradation of gaskets after over 20 years of exposure to chloramine residuals. Components
13   with higher surface area to volume ratios such as flappers or valve seats may experience more
14   significant deterioration.
15
16   Reiber (1993) noted that deterioration by monochloramine is less noticeable than by
17   dichloramine. Therefore maintaining a high chlorine to ammonia ratio may help prevent
18   material deterioration as well as help control nitrification. Both Reiber (1991) and Bonds (2004)
19   found that fluorocarbon elastomers showed the least corrosion of the elastomers tested.
20   Therefore, using fluorocarbon elastomers in components that will receive high exposure to
21   chloramines will help prevent failure.
22
23   Recommendations for Addressing this Issue
24
25   Systems can minimize lead corrosion by:
26
27   •   Optimizing the pH, alkalinity and dissolved inorganic carbon (DIC) of the water
28
29   •   Adding a corrosion inhibitor (i.e., a substance that is phosphate- or silica-based) to the
30   finished water to form a protective coating on the pipes
31
32   Systems concerned with brass corrosion can take steps to limit free ammonia and nitrification as
33   listed in the section on nitrification. The steps listed above will also help mitigate brass
34   corrosion.
35
36   To prevent elastomer corrosion, components such as gaskets and flappers should be made
37   of elastomers such as fluorocarbons that have good resistance to chloramines. Education and
38   outreach programs can help customers select the appropriate materials.
39
40   *Taste and Odor Issues*
41
.

1   Chlorine based disinfectants have some taste and odor impact associated with them.
2   Monochloramine has a higher odor threshold and variations in residual concentrations produce
3   less noticeable odors than free chlorine. Dichloramine and trichloramine, however, have much
4   stronger odors than either monochloramine or free chlorine (Krasner and Barrett 1985). Taste
5   and odor problems can also arise from nitrification episodes caused by excess ammonia. Control
6   measures to prevent nitrification are discussed earlier in this section.
7
8   Recommendations for Addressing this Issue
9
10   To prevent the formation of dichloramine and trichloramine that cause taste and odor
11   problems, the chlorine to ammonia ratio should be carefully controlled and pH should be kept
12   above 7.0. When the chlorine to ammonia ratio exceeds 5:1, dichloramine frequently begins to
13   form. In general, maintaining a ratio between 3:1 and 5:1 should minimize odor problems.
14
15   *Blending Chloraminated Water with Chlorinated Water*
16
17   When water with a chloramine residual is mixed with water with a free chlorine residual,
18   the chlorine to ammonia ratio changes and the resulting changes in distribution system water
19   quality may cause customer complaints and/or possible violations of SDWA regulations. If the
20   additional free chlorine raises the ratio to higher than 5:1, dichloramine and trichloramine can
21   form which have low odor thresholds and can cause customer complaints. If the ratio is raised to
22   7.6:1 or higher by the additional free chlorine residual, breakpoint reactions can occur.
23   Breakpoint reactions can lead to a total loss of residual, which can result in a violation of the
24   SWTR and possibly the TCR. Blending could also cause the water to have excess free chlorine,
25   causing DBP formation and a possible violation of the DBPR.
26
27   Recommendations for Addressing this Issue
28
29   To avoid breakpoint chlorination, utilities mixing waters with chloramines and free
30   chlorine residuals should determine the residuals in both waters and determine the chlorine to
31   ammonia ratio of the resulting mixture. Some systems have developed computer models to
32   predict these ratios. The models need to be calibrated to the specific distribution system in order
33   to be useful. Keeping the chlorine to ammonia ratio below 5:1 in the chloraminated water, which
34   allows an ammonia residual to exist, will allow some addition of water with a chlorine residual
35   before problems occur. A system could also choose to add ammonia again at the point where the
36   waters are mixed to maintain the chlorine to ammonia ratio in the proper range. In either case,
37   the water system also needs to take into account the possibility of excess ammonia causing
38   nitrification. Careful monitoring of excess ammonia, free chlorine, and total chlorine residuals
39   should be carried out to ensure that appropriate ratios are maintained.
40
41   *Weaker Disinfectant*

.

1
2   Chloramines are a weaker disinfectant than free chlorine. Exhibit 5.1 displays the CT
3   required for free chlorine and chloramines to achieve inactivation of viruses and *Giardia* cysts.
4   Both chlorine and chloramines are ineffective against *Cryptosporidium* oocysts.
5
6
7   **Exhibit 5.1 Comparison of CT (mg-min/L) values for Inactivation of Viruses and**
8   **_Giardia_ by Free Chlorine and Chloramines at pH 7 and 10°C**
9

Disinfectant	2-log inactivation (99%) of viruses	4-log inactivation (99.99%) of viruses	0.5-log inactivation (68.4%) of _Giardia_	3.0-log inactivation (99.9%) of _Giardia_
Chlorine	3	6	17[1]	104[1]
Chloramines	643	1491	310	1850

10
11   [1] CT values are for free chlorine of <0.4 mg/L
12
13
14   Even at relatively high doses of chloramines, extremely long residence times are required
15   to achieve required levels of inactivation for viruses and *Giardia* cysts using chloramines alone.
16   Systems that switch from free chlorine to chloramines as their primary disinfectant must
17   benchmark for viruses and *Giardia*.
18
19   <u>Recommendations for Addressing this Issue</u>
20
21   Systems can compensate for the lower disinfection power of chloramines by using a
22   different disinfectant as a primary disinfectant and using chloramines to maintain a disinfectant
23   residual in the distribution system. Frequently this is done by adding the ammonia some time
24   after the chlorine has been added. This allows a period of time for free chlorine disinfection.
25   While this scheme will result in higher DBPs than using chloramines as the primary disinfectant,
26   it will still result in lower DBP concentrations than when free chlorine is used as both a primary
27   and residual disinfectant. One water system found as little as a two minutes of free chlorine
28   contact time achieved desired inactivation results and reduced TTHM by 50 percent over free
29   chlorine alone (Means et al. 1986). Another system found it could have as much as an hour of
30   free chlorine contact time before converting to chloramines without exceeding TTHM regulatory
31   levels (Gianatasio 1985).
32
33   Systems with very high total organic carbon (TOC) may wish to avoid free chlorine
34   altogether. These systems can switch to a different primary disinfectant such as ozone, UV, or
.

.

1   chlorine dioxide. See Sections 5.2, 5.3, and 5.4 for more details on these disinfectants, and their
2   advantages and drawbacks.
3
4   *Safety Concerns*
5
6   There are safety issues that need to be considered when switching to chloramines. They
7   will vary somewhat depending on the type of ammonia used. Ammonia, if it reacts with chlorine
8   in high concentrations, can form an explosive mixture of trichloramine. Ammonia gas is also
9   toxic if released to the atmosphere in sufficient concentrations. Ammonium sulfate does not
10   have as many safety issues as either anhydrous ammonia or aqueous ammonia, but it is
11   considerably more expensive and must be kept dry to avoid feed problems.
12
13   Recommendations for Addressing this Issue
14
15   To avoid the possibility of an explosive reaction between bulk chlorine and bulk
16   ammonia, the two chemicals should be stored in separate rooms. Feed points and pipes for
17   chlorine and ammonia should also be placed at least five feet apart (USEPA 1999b).
18
19   To avoid the release of ammonia into the atmosphere, several precautions should be
20   taken. Anhydrous ammonia should be stored in pressurized containers away from temperature
21   extremes (temperatures greater than 125^oF will cause pressure buildups in the tank). Aqueous
22   ammonia tanks should be vented to keep pressure from building up from ammonia volatilization.
23   Keeping the temperature low will also help to prevent volatilization, which can cause vapor lock
24   in pumps. Buildings where ammonia is stored should be well ventilated and respirators should
25   be stored just outside the ammonia storage area. If large amounts of ammonia are stored an
26   emergency scrubber should installed as well.
27
28   *Ozone and GAC Issues*
29
30   Wilczak et al. (2003) found that ozone use prior to chloramination could destabilize the
31   chloramine residual, leading to problems with residual concentrations at the ends of the
32   distribution system. The loss of residual was attributed to the increased assimilable organic
33   carbon (AOC) resulting from ozonation.
34
35   Adding chloramines before a GAC filter may lead to nitrification in the GAC filter. It
36   has been found that a reaction between chloramines and GAC may free up ammonia and
37   encourage the growth of ammonia oxidizing bacteria in the GAC filters (Tokuno 1999).
38
39   Recommendations for Addressing this Issue
40

.

.

1   Installing a GAC filter after ozone, then allowing a few minutes of free chlorine contact
2   time to oxidize any organics before ammonia is added can be a more reliable way to allow the
3   formation of a stable chloramine residual. Chloramines should not be added prior to GAC
4   filters.
5
6   *Issues for Dialysis Patients, Fish Owners, and Other Customers*
7
8   Chloramines can be toxic to dialysis patients and must be removed before water is used
9   in dialysis machines. Chloramines are also toxic to fish and therefore must be removed from the
10 water before it is used for pet fish or before water is discharged to natural fish habitats. The
11 removal of chloramines from tap water is more difficult to achieve, and more costly, than free
12 chlorine. This also impacts water customers who produce foods, beverages, and
13 pharmaceuticals.
14
15   Recommendations for Addressing this Issue
16
17   Because the process for removing chloramines is different from that for removing
18 chlorine, dialysis patients and fish owners should be notified in advance of the switch to
19 chloramines. Water systems may also want to consider adding special notification language for
20 fish owners and dialysis patients to their consumer confidence reports, so that the information is
21 provided on an annual basis. Information on how other systems conducted community outreach
22 before, during, and after treatment with chloramines are presented in the AWWARF document,
23 *Optimizing Chloramine Treatment, Second Edition* (Kirmeyer et al., 2004a).
24
25 **5.1.3   Recommendations for Gathering More Information**
26
27 *Read Case Studies*
28
29   Two case studies in Appendix B address simultaneous compliance issues associated with
30 using chloramines. Both of the systems described in these case studies switched to chloramines
31 as part of an effort to reduce DBP concentrations.
32
33   ***Case Study #9 - Modifying Chloramination Practices to Address Nitrification Issues*** on
34 page B- 57 describes a surface water system serving 115,000 people that took steps to address
35 nitrification and potential total coliform problems in the distribution system after switching to
36 chloramines. ***Case Study #14 - Chlorine Dioxide for Primary Disinfection and Chloramines***
37 ***for Secondary Disinfection*** on page B-89 describes a small surface water system that achieves
38 its CT with chlorine dioxide and maintains its disinfectant residual in the distribution system
39 with chloramines.
40
41 *See Additional References*
.

.

1
2   Readers can turn to Chapter 7 for more references on this topic. Section 7.1.1 includes
3   general references on water treatment, Section 7.1.2 includes references on controlling DBP
4   formation, and section 7.1.12 includes references on chloramines. Section 7.1.3 includes several
5   references on corrosion/disinfection interrelationships.
6
7   *Consider Additional Monitoring*
8
9   The following are some suggestions for additional monitoring that may benefit water
10   systems using chloramines. The purpose of these monitoring suggestions is specifically to
11   address and prevent potential simultaneous compliance issues. Water system managers should
12   discuss process control monitoring with the manufacturer of their units or their engineer.
13
14   ✓ Systems should consider a monitoring program targeted at identifying the potential for
15   nitrification. Primary monitoring parameters should include:
16
17   ◆ Chemical balance of nitrogen species: This can be determined by measuring the free
18   and total ammonia, nitrate, and nitrite concentrations, and calculating the differences
19   between the treatment plant finished water and a given point in the distribution
20   system.
21
22   ◆ Heterotrophic plate counts (HPC). Standard plate counts may be useful, but they are
23   not as sensitive to changes as counts using the R2A agar. (Kirmeyer et al. 1995)
24   recommends the use of R2A agar for HPC analysis for all utilities practicing
25   chloramination.
26
27   ◆ Chloramine (or total chlorine) residual: A sharp decrease in the chloramine residual
28   could signal the onset of nitrification. However, caution needs to be exercised since
29   chloramine residuals degrade over time in open reservoirs in the presence of biofilm
30   and under other distribution system conditions, such as backflow incidents.
31   Chloramine residual monitoring is required by the SWTR and Stage 1 D/DBPR.
32
33
34   ✓ Other monitoring parameters (i.e., those which should not be used without corroboration with
35   a primary parameter) include the following:
36
37   ◆ Dissolved Oxygen (DO): Decreases in DO levels frequently correlate with
38   nitrification in some utilities.
39
40   ◆ Customer complaints: monitoring customer complaints can identify problem areas to
41   monitor for signs of nitrification.
42

.

.

1   The following water system locations should be monitored to ensure the proper use of
2   chloramines and nitrification control:
3

4   ◆ Raw water
5   ◆ Treatment plant finished water
6   ◆ Reservoirs
7/8   ◆ Dead-end mains
9   ◆ Designated coliform monitoring locations
10

11   *Consider Other Tools*
12

13   In addition to water quality monitoring, there are additional tools listed in Chapter 6 to
14   help systems evaluate and improve their current water system in relation to the compliance issues
15   they may face when modifying their treatment operations. Examples of tools that can be used
16   when chloramines are used for Stage 2 DBPR compliance include:
17

18   • The "Guidance Manual for Monitoring Distribution System Water Quality"
19   (Kirmeyer 2002) which can be used to assist water utilities in implementing a
20   distribution system water quality data collection and analysis program.
21

22   • The AwwaRF report "Internal Corrosion of Water Distribution System" (AWWARF
23   and DVGW-Technologiezentrum Wasser 1996) which provides bench-scale and pilot
24   testing protocols that can be used to evaluate changes in corrosion potential due to the
25   switch to chloramines.
26

27   • The AwwaRF report "Optimizing Corrosion Control in Water Distribution System"
28   (Duranceau et al. 2004) which provides techniques for instantaneous corrosion
29   monitoring
30

31   • The AwwaRF report "Water Utility Self-Assessment for the Management of
32   Aesthetic Issues" (McGuire et al. 2004) which can be used to guide utilities in
33   conducting a self-assessment of their taste and odor issues associated with ozonation
34   and to identify subsequent control strategies.
35

36   • The AwwaRF report "Tools and Methods to Effectively Measure Customer
37   Perceptions" (Colbourne 2001) which describes tools that allow utilities to measure
38   customer perceptions and changes in their opinions toward the use of chloramines.
39

40   Readers are encouraged to read through Chapter 6 before making any final compliance decisions.
41

.

.

1   **5.2   Ozonation**

2

3   Ozone is a powerful chemical disinfectant and an alternative to free chlorine. It is an
4   unstable gas that is generated on-site, using either air or liquid oxygen. It is very effective at
5   disinfecting many microbes and as a pre-oxidant. It can, however, convert bromide to bromate, a
6   DBP regulated by the Stage 1 D/DBPR. It also oxidizes organic matter into smaller molecules,
7   which can provide a more easily degradable food source for microorganisms in the distribution
8   system. Ozone can also produce odor compounds such as aldehydes and ketones.

9

10   **5.2.1   Advantages of Ozonation**

11

12   The main advantages of ozone are:

13

14   • **Effective against pathogens**

15

16   • **Does not form chlorinated DBPs**

17

18   • **Effective pre-oxidant**

19

20   • **Can raise UV transmittance of water and UV disinfection effectiveness**

21

22   • **Independent of pH**

23

24   • **Can aid coagulation**
25

26

27   *Effective Against Many Microbes*

28

29   Ozone is a highly effective disinfectant because of its high oxidation potential. It is the
30   strongest of all the commonly used chemical disinfectants. It is most effective against viruses
31   and slightly less effective against *Cryptosporidium* oocysts. Exhibit 5.2 shows the required CT
32   values for inactivation of various microbes for each of the commonly used chemical
33   disinfectants.

34

35

.

.

1   **Exhibit 5.2 CT values (mg-min/L) for Chemical Disinfectants at 10°C**
2

Disinfectant	4-log Inactivation (99.99%) of Viruses	3-log Inactivation (99.9%) of *Giardia*	3-log Inactivation (99.9%) of *Cryptosporidium*
Ozone	1	1.43	30
Chlorine[1]	6	104	N/A
Chloramine[2]	1,491	1,850	N/A
Chlorine Dioxide	4.2	23	830

3   Source: USEPA 2003a
4   N/A - these disinfectants are ineffective against *Cryptosporidium*
5   [1] at pH = 7.0 and chlorine residual = 0.4 mg/L
6   [2] for pH values 6 through 9
7
8

9   In addition to satisfying microbial disinfection requirements, ozone can aid in compliance
10 with the Stage 2 DBPR by eliminating chlorine as a primary disinfectant and lowering the
11 required dose of secondary disinfectant. Systems that switch to ozone from another primary
12 disinfectant are required to benchmark for *Giardia*, *Cryptosporidium*, and viruses.
13

14 *Does Not Form Chlorinated DBPs*

15

16   Ozone by itself does not form chlorinated DBPs. Therefore using ozone can lower DBP
17 formation and aid in compliance with the Stage 2 DBPR. If chlorine is used as a secondary
18 disinfectant after ozone, higher concentrations of chloroform can be formed, although total
19 TTHM levels will generally be lower than if chlorine is used as both a primary and secondary
20 disinfectant. Ozone can react with bromide, however, to form bromate, which has a MCL of 10
21 ppb set under the Stage 1 D/DBPR.
22

23 *Effective Pre-oxidant*

24

25   Ozone's high oxidation potential also means it acts well as a pre-oxidant. It can be used
26 to oxidize iron and manganese so they can be removed through coagulation and sedimentation.
27 It also oxidizes arsenic. Oxidizing arsenic (III) to arsenic (V) enhances removal of arsenic and
28 aids in compliance with the recently lowered MCL for arsenic. Many organic compounds are
29 oxidized by ozone as well. It is especially useful in oxidizing taste and odor compounds such as
30 geosmin and 2 -methylisoborneol (MIB). The efficiency of ozone at degrading geosmin and

.

1   MIB is further increased if hydrogen peroxide is added in addition to the ozone, a process
2   referred to as peroxone. If the dose is high enough, ozone can even completely mineralize some
3   organics, lowering the concentration of DBP precursors and aiding in Stage 2 DBPR compliance.
4
5   *Raises UV Transmittance of Water*
6
7   Low UV transmittance of the water will lead to less efficient UV disinfection. Ozone
8   treatment before UV can oxidize those compounds that absorb UV, thereby increasing
9   transmittance and UV's disinfection effectiveness. Although it is not recommended that a
10 system install both UV and ozone, a system with ozone in place that is limited by the ozone dose
11 it can apply because of bromide may want to consider UV after ozonation to achieve the required
12 *Cryptosporidium* disinfection.
13
14 *Independent of pH*
15
16   The disinfection efficiency of ozone, unlike chlorine, does not depend on pH for the
17 range of pH values normally encountered in water treatment. This enables plants to adjust pH to
18 optimize coagulation, prevent corrosion, or alter DBP formation reactions without having to
19 worry about loss of disinfection capability. It also removes some of the seasonal variability that
20 is usually found in disinfection benchmarks. Note, however, that bromate formation is impacted
21 by the pH of the water. This is discussed in more detail later in this section.
22
23 *Can Aid Coagulation*
24
25   Some systems have reported improvements in coagulation when they switched to adding
26 ozone prior to coagulation (Reckhow et al. 1993, Stolarik and Christie 1997). Other systems
27 have found no change or even increases in filtered water turbidity after ozonation. The
28 interaction between ozonation and coagulation is complex and entails the interaction of many
29 parameters. Therefore, results will vary significantly from plant to plant. Systems should
30 conduct bench scale and preferably pilot scale tests to determine how ozone will affect the
31 systems water quality.
32
33 **5.2.2   Potential Operational and Simultaneous Compliance Issues Associated with**
34 **Ozonation**
35
36   The main operational and simultaneous compliance issues associated with ozone are:
37
38
39   • **Forms bromate**
40
41   • **Forms smaller organic compounds**
42
.

1   • **Does not provide a residual**
2
3   • **Introduces dissolved oxygen into the water**
4
5   • **Can form taste and odor compounds**
6
7   • **Can increase corrosion**
8
10   • **Ozone bubbles can hinder filter performance**
11
12   • **Requires additional training**
13
14   This section summarizes these issues and provides recommendations for some ways to
15   address them.
16
17   *Forms Bromate*
18
19   Ozone reacts with bromide to form bromate. In the presence of organic matter, ozone
20   can also form brominated THMs and HAAs. The Stage 1 D/DBPR requires compliance with a
21   10 µg/L MCL for bromate. Therefore, systems considering installing ozone should evaluate
22   whether compliance with the bromate MCL may be an issue.
23
24   Whether bromate or brominated organic DBPs form depends on the pH and organic
25   content of the water. Lower pH water and high DOC concentrations tend to favor the formation
26   of brominated organic compounds. Systems using ozone may be able to reduce their chlorine
27   dose, however, and as a result improve compliance with TTHM and HAA5 MCLs. Higher pH
28   and low dissolved organic concentration generally lead to greater bromate formation.
29
30   Recommendations for Addressing this Issue
31
32   There are several techniques that public water systems can use to control disinfection
33   byproduct formation when bromide ion is present. These include:
34
36   • Lowering the pH
37
38   • Keeping the ratio of ozone to DOC low
39
40   • Adding ammonia
41
43   • Adding hydrogen peroxide

.

1
2   Lowering the pH favors formation of brominated organic compounds over bromate.
3   Performing ozonation at a pH below 7 will lower the formation of bromate. This is a particularly
4   good option for systems that have low DOC concentrations and do not have problems with high
5   TTHM or HAA5 concentrations in their finished water. If DOC concentrations are high,
6   however, this method of bromate control may result in exceeding HAA5 or TTHM MCLs.
7   Systems also need to consider other effects of lowering pH such as increased corrosion, impacts
8   on the effectiveness of secondary disinfectants, and impacts on coagulation. See Section 3.2 for
9   a more complete discussion of the effects of changing pH.
10
11   If the ratio of ozone to DOC is kept low, the formation of bromate and brominated
12 organic compounds can be reduced. This can be done by either lowering the ozone dose while
13 extending the contact time, or by lowering DOC concentrations. If a system does not need to use
14 ozone for pre-oxidation, it may want to add the ozone after sedimentation, or even after filtration,
15 to achieve a lower ozone to DOC ratio. It is not typical, however, to ozonate after filtration. If a
16 system needs to pre-oxidize, a small dose of ozone can be added to the raw water and a higher
17 dose added after sedimentation or filtration. Using biological filtration in this case can be
18 especially effective for lowering DBPs, since biological filtration tends to remove aldehydes and
19 other small organic compounds that can make up a large fraction of the DOC.
20
21   Adding ammonia to water containing bromide and ozone will lead to bromamine
22 formation. Bromamines react more slowly with organic matter and form fewer brominated
23 organic compounds and less bromate. Ammonia addition, however, can lead to nitrification
24 problems in the distribution system. See Section 5.1 for more details on controlling nitrification
25 when ammonia is added.
26
27   Adding hydrogen peroxide in addition to ozone shifts the oxidation pathway from one
28 that depends on reacting with molecular ozone to one that depends on hydroxyl radical reactions.
29 One effect of this shift may be a lower concentration of brominated organic compounds in the
30 treated water.
31
32   Methods described above can help control DBP formation for systems with bromide in
33 their source water. Systems with high bromide concentrations, especially those with high DOC
34 as well, may not be able to use ozone even if they adopt these mitigation methods. Systems that
35 use ozone to inactivate *Cryptosporidium* may have an especially hard time, in this regard,
36 because *Cryptosporidium* requires a much higher ozone dose. Since the LT2ESWTR does not
37 grant disinfection credit for an ozone residual in the first contact chamber, many systems will
38 want to increase their ozone dose to help them gain CT in subsequent chambers. Bromide can be
39 removed by the use of anion exchange, but this is generally not a cost-effective solution.
40

.

.

1   *Forms Smaller Organic Compounds*
2
3   Ozone breaks down organic compounds into smaller chain organic molecules, especially
4   aldehydes and ketones. These smaller organic molecules are more readily biodegradable and can
5   increase biological growth downstream of the ozone addition point. AOC is a measure of the
6   organic carbon readily available as food for microorganisms. Some systems that have added
7   ozone without biological filtration have experienced increased AOC and microbial growth in the
8   distribution system (Van der Kooij 1997). Increased biological growth in the distribution system
9   can lead to higher disinfectant demand and more frequent TCR violations. Biological growth
10 can also cause increased corrosion, possibly leading to violations of the Lead and Copper Rule
11 (LCR) as well as to taste and odor problems.
12
13   Recommendations for Addressing this Issue
14
16   An effective way to reduce
18 AOC and prevent increasing
20 biological growth in the distribution
22 system is to remove it using
24 biologically active filters. Odor
26 compounds can be removed along

> **An effective way to reduce AOC and prevent increasing biological growth in the distribution system is to remove it using biologically active filters.**

27 with the AOC. Biological filtration can be achieved by not having a disinfectant residual in the
28 water entering the filter. The increased dissolved oxygen that results from the ozonation,
29 combined with the high surface area per volume of the filter media, provide conditions for
30 biological growth to occur on the filters. The biological growth on the filters then consumes the
31 AOC, using it as a food source. Biological filtration has been shown to lower AOC effectively,
32 even when very short residence times are used. Longer residence times can lead to the reduction
33 of other organic compounds as well (LeChevallier et al. 1992). See Urfer et al. (1997) for more
34 details on biological filtration.
35
36   Any type of filter media can accommodate biological filtration. Slow sand filters, rapid
37 rate dual media filters, and GAC filters have all been successfully used for biological filtration.
38 Rapid rate filters have been shown to remove AOC, though they may not remove all of the
39 biodegrable dissolved organic carbon (BDOC), which is a portion of organic matter that can still
40 be used by microbes as a food source but takes longer for the microbes to metabolize than AOC.
41 Slow sand filters and GAC contactors have been shown to remove both BDOC and AOC. GAC
42 has the added benefit that it will adsorb or concentrate organics, thus extending the time
43 available for the microbes to metabolize the organic matter.
44
45 *Does Not Provide a Disinfectant Residual*
46

.

.

1   Ozone reacts very quickly and therefore is not able to provide a residual for use in the
2   distribution system. It is also volatile and can be lost in pumps and other equipment with high
3   flow turbidity. A secondary disinfectant is, therefore, required to maintain a disinfectant residual
4   in the distribution system as required by the SWTR.
5
6   Recommendations for Addressing this Issue
7
8   Chlorine can often be used as an effective residual disinfectant after ozonation. Since
9   ozone is used to achieve primary disinfection, lower doses of chlorine can be used, resulting in
10   lower DBP levels. Ozone followed by biological filtration reduces DBP precursors, which also
11   leads to lower DBP levels. If biological filtration is not used, the system should be careful that
12   chlorine addition after ozonation does not result in higher DBP levels than if chlorine alone were
13   added. Chloroform is of particular concern in this situation.
14
15   Chloramines can also be used to provide a distribution system residual after ozonation.
16   Chloramines will result in lower DBPs than chlorine. As mentioned above, adding ammonia
17   with the ozone will provide benefits regarding the formation of brominated DBPs. If this
18   approach is taken, chlorine can be added after filtration to form the chloramines. For a full
19   discussion on the benefits and drawbacks of chloramines as a secondary disinfectant, see Section
20   5.1.
21
22   *Introduces Dissolved Oxygen into the Water*
23
24   When ozone reacts in water it forms dissolved oxygen. Oxygen can increase corrosion of
25   metals. It can also cause increased growth of aerobic bacteria and problems with TCR
26   compliance.
27
28   Recommendations for Addressing this Issue
29
30   Corrosion-resistant materials should be used in the ozone feed equipment, the contact
31   chamber, and any other plant equipment that comes into contact with the water after ozonation
32   and before the dissolved oxygen is dissipated. The best way to prevent dissolved oxygen from
33   entering the distribution system is to run the filters in biologically active mode. This will lower
34   the dissolved oxygen, as well as remove AOC.
35
36   Systems using ozone after filtration and unfiltered systems may need to take steps to
37   control microbial growth in the distribution system. Control measures include ensuring a
38   sufficient residual throughout the system, looping dead ends in the distribution system, and
39   minimizing retention time in reservoirs. Systems may also want to raise the pH of the water or
40   add a corrosion inhibitor to prevent corrosion.
41
.

.

1   *Can Form Taste and Odor Compounds*
2
3   Ozonation of organic matter forms aldehydes and other compounds that can impart tastes
4   and odors to water.
5
6   Recommendations for Addressing this Issue
7
8   Systems should consider using a GAC filter or biologically active filtration to help
9   eliminate aldehydes formed during ozonation, before the water reaches customers.
10
11   *Increases Corrosion*
12
13   Ozone is corrosive and can corrode steel pipes and fittings, concrete, rubber gaskets and
14   other material with which it comes into contact in the treatment plant.
15
16   Recommendations for Addressing this Issue
17
18   All material that comes into contact with an ozone residual should be resistant to ozone.
19   Equipment manufacturers should be contacted to ensure compatibility of their equipment with
20   ozone.
21
22   *Ozone Bubbles Can Hinder Filter Performance*
23
24   Ozone can de-gas in the filter and bind to the filter media. This can adversely affect filter
25   performance and reduce the effectiveness of filter backwashing.
26
27   Recommendations for Addressing this Issue
28
29   If ozone is injected under pressure, it should be de-gassed before the filters.
30
31   *Requires Additional Training*
32
33   Ozone disinfection is an advanced technology and requires different procedures and
34   equipment than most operators are familiar with.
35
36   Recommendations for Addressing this Issue
37
38   Additional training will be needed to ensure that operators can use equipment correctly.
39   Operators should also be aware of safety concerns related to off-gassing and destruct units.
40

.

.

1   **5.2.3   Recommendations for Gathering More Information**
2
3   *Read Case Studies*
4
5   Two case studies in Appendix B describe simultaneous compliance challenges faced by
6   utilities using ozone.
7
8   *Case Study #10 - Ozonation* on page B-63 describes a surface water system serving
9   approximately 115,000 people that installed ozone to control both *Cryptosporidium* and
10   disinfection byproducts. The system was concerned about how ozone might result in increased
11   AOC in its finished water, so biofiltration was also installed to address potential problems that
12   could have arisen in the distribution system as a result.
13
14   *Case Study #11 – Ozonation and Biological Filtration* on page B-71 describes a system
15   that significantly expanded its capacity at the same time that it installed ozone. Its source is a
16   river with high TOC, so this system was also concerned with ozone's impact on AOC levels in
17   the finished water. Four new biological filters were installed and 12 existing filters were
18   converted to biological filtration.
19
20   *See Additional References*
21
22   Readers can turn to Chapter 7 for more references on this topic. Section 7.1.1 includes
23   general references on water treatment, Section 7.1.2 includes references on controlling DBP
24   formation, and Section 7.1.13 includes references on Ozone.
25
26   *Consider Additional Monitoring*
27
28   The following are some suggestions for additional monitoring that may benefit water
29   systems using ozone. The purpose of these monitoring suggestions is specifically to address and
30   prevent potential simultaneous compliance issues. Water system managers should discuss
31   process control monitoring with the manufacturer of their ozonation units or their engineer.
32
33   ✓ Dissolved organic carbon (DOC) measurements in water being ozonated, and
34   calculation of the ozone: DOC ratio. By keeping the ozone: DOC ratio low,
35   formation of bromate and brominated organic compounds can be reduced.
36
37   ✓ AOC and/or BDOC monitoring after biological filtration to verify that they are being
38   removed reliably.
39
40   ✓ If there is no biological filtration treatment step, AOC and/or BDOC monitoring of
41   finished water before it enters the distribution system to track whether levels are high

.

.

1   enough to cause problems with biofilm growth.
2
3   ✓ HPC measurements at locations throughout the distribution system and in plant
4   effluent, to watch for increased biofilm growth.
5
6   ✓ Dissolved oxygen at points after ozonation in the treatment plant, as part of an effort
7   to control levels and limit corrosion in the plant.
8
9   ✓ Dissolved oxygen at entry points to the distribution system to make sure it has been
10   reduced to acceptable levels and will not induce distribution system corrosion.
11
12   ✓ Taste and odor in finished water since ozonation can create off-odors.
13
14   ✓ Ozone residual in the contactor to ensure proper CT, and after the contactor to ensure
15   proper removal and safety.
16
17 *Consider Other Tools*
18
19   In addition to water quality monitoring, there are additional tools available in Chapter 6
20 to help systems evaluate and improve their current water system in relation to the compliance
21 issues they may face when modifying their treatment operations. Examples of tools that can be
22 used when ozone is used for Stage 2 DBPR compliance include:
23
24   • The "Guidance Manual for Monitoring Distribution System Water Quality"
25   (Kirmeyer 2002) which can be used to assist water utilities in implementing a
26   distribution system water quality data collection and analysis program
27
28   • The AwwaRF report "Internal Corrosion of Water Distribution System" (AWWARF
29   and DVGW-Technologiezentrum Wasser 1996) which provides bench-scale and pilot
30   testing protocols that can be used to evaluate changes in corrosion potential due to the
31   switch to ozonation
32
33   • The AwwaRF report "Optimizing Corrosion Control in Water Distribution System"
34   (Duranceau et al. 2004) which provides techniques for instantaneous corrosion
35   monitoring
36
37   • Various cost estimation models that can be used to estimate the cost of designing,
38   constructing, and operating a new ozonation facility
39
40   • The AwwaRF report "Water Utility Self-Assessment for the Management of
41   Aesthetic Issues" (McGuire et al. 2004) which can be used to guide utilities in
.

.

1   conducting self-assessment of taste and odor issues caused by ozonation and to
2   identify subsequent control strategies; and
3
4   •   The AwwaRF report "Tools and Methods to Effectively Measure Customer
5   Perceptions" (Colbourne 2001) which describes tools that allow utilities to measure
6   customer perceptions and changes in their opinions toward the use of ozonation.
7
8   Readers are encouraged to read through Chapter 6 before making any final compliance decisions.
9

.

1   **5.3   Ultraviolet Light (UV)**

2

3   Recent research indicating that UV light can inactivate *Cryptosporidium* at relatively low
4   lamp intensities (Bukhari et al. 1999) has spurred interest in its use for drinking water
5   disinfection. UV light works by damaging the genetic material of microorganisms, interfering
6   with the ability of pathogens to replicate and therefore with their ability to be infective. Similar
7   to chemical disinfectants, the extent of UV inactivation depends on the intensity of the light and
8   the time the microorganism is exposed to it. UV is an effective way to disinfect without
9   producing regulated DBPs.

10

11   **5.3.1   Advantages of UV**

12

13   *Advantages*

14

15   UV light's advantages include:

16

18   • **It can inactivate chlorine-resistant pathogens such as *Cryptosporidium* oocysts**
19   **and *Giardia* cysts at relatively low intensities**

20

21   • **It does not produce regulated DBPs**

22

23   • **Its effectiveness is not pH or temperature dependent**

25

26   *Inactivates Cryptosporidium and Giardia*

27

28   UV disinfection gained attention in the U.S. drinking water market when it was shown
29   that it could inactivate *Cryptosporidium* oocysts and *Giardia* cysts. This gives UV an advantage
30   over chlorine or chloramines, which are ineffective against *Cryptosporidium*. If properly tested
31   and validated, UV is one of the least expensive options for systems that are required to achieve
32   additional *Cryptosporidium* inactivation under the LT2ESWTR (U.S. EPA 2003b). UV can also
33   meet IESWTR requirements for *Giardia* inactivation.

34

35   *Does Not Produce Regulated DBPs*

36

37   UV disinfection, as a photochemical process, does not produce any of the regulated
38   byproducts that chemical disinfectants such as chlorine, ozone, and chlorine dioxide produce.
39   Systems may meet Stage 2 DBPR requirements by switching to UV disinfection and lowering
40   their doses of chemical disinfectants. Systems making this change will be required to benchmark
41   their disinfection process under LT2ESWTR requirements before making the change. See the
42   Section 5.3.2 for further discussion of UV benchmarking requirements. Systems will also need
43   to continue to meet the residual disinfection requirements of the SWTR.

.

1
2   *Not pH or Temperature Dependent*
3
4   UV disinfection, because it is a physical rather than a chemical process, does not vary in
5   efficiency with changes in pH or temperature. This means that the dose will not need to be
6   changed seasonally, as temperature and pH vary, to maintain constant disinfection efficiency as
7   is required for chlorine and other chemical disinfectants. It also gives systems more flexibility to
8   adjust pH to control coagulation, or to lower production of DBPs without also affecting
9   disinfection efficiency. Because the disinfection provided is not as affected by seasonal changes
10   in water temperature or pH, systems benchmarking may see a smaller difference in CT between
11   minimum and maximum months, requiring less of a safety factor to ensure meeting the
12   benchmark. This will depend somewhat on how flows vary for the system over the year.
13
14   **5.3.2   Potential Operational and Simultaneous Compliance Issues Associated with UV**
15   **Disinfection**
16
17   A main drawback with UV is the possibility of microbes passing through at times the
18   lamp is operating off specification, which may be difficult to detect using traditional water
19   quality monitoring methods. Complete lamp failures are a serious problem and are discussed at
20   the end of this section. UV reactors must be validated according to state guidelines and operate
21   within the validated parameters at least 95 percent of the time (or more often if specified by the
22   state). Lamps operating within the required LT2ESWTR validation parameters can still cause
23   problems during shorter periods of off-specification operation. At low UV intensities, some
24   microbes have shown the ability to repair damage done by UV light. Because of this, even
25   decreases in lamp intensity not enough to cause a violation of disinfection requirements may
26   allow microbes into the distribution system where they can repair themselves, colonize biofilms,
28   and cause problems with TCR compliance.
30   Therefore any periods of the lamp operating
32   off specification should be minimized.
34
36   Potential operational and
38   simultaneous compliance issues associated
39   with UV disinfection include:
40
42   • **Substances in water can interfere with UV disinfection**
43
44   • **Hydraulic upsets can lower the delivered dose and possibly cause lamp breakage**
45
46   • **Much higher doses needed for virus inactivation**
47
48   • **UV disinfection provides no distribution system residual**

> **A main drawback with UV is the possibility of microbes passing through when the lamp is operating off specification**.

.

.

1
2   •   **Power outages can cause loss of disinfection**
3
4   •   **Requires additional training**
5
6 This section provides brief descriptions of these issues and suggestions for addressing them.
7
8 *Substances in Water Can Interfere with UV Disinfection*
9
10   Because UV disinfection relies on UV light interacting with the organism's genetic
11 material to be effective, any substance that either absorbs or refracts the UV light in the
12 germicidal range of 200 to 300 nanometer wavelengths can interfere with disinfection.
13 Chemicals with the potential to do this include:
14
15   •   dissolved organic carbon (DOC)
16   •   iron
17   •   manganese
18   •   calcium
19   •   aluminum
20   •   ozone
21
22 There are several possible sources of these materials, each having its own implications for
23 simultaneous compliance. These sources include:
24
25   •   raw water
26   •   coagulants
27   •   other treatment chemicals
28
29 Chemicals used in water treatment that can also absorb UV light include iron based coagulants,
30 some polymers, and ozone.
31
32   If chlorine dioxide is used in addition to UV, it can react with UV light to form chlorate.
33 This carries with it two consequences: first all chlorine dioxide residual will be lost in the UV
34 reactors reducing chlorine dioxide CT; and chlorate, which is not itself regulated, can react to
35 form the regulated DBP chlorite. Note that there are no known effects of passing water with
36 chlorine or chloramine residual through UV reactors.
37
38   Many of the same compounds that absorb light can also cause fouling of UV lamp
39 sleeves and reduce disinfection efficiency. In addition to iron, manganese, and DOC, calcium
40 (including that found in corrosion inhibitors), magnesium, and aluminum can also cause fouling.

.

.

1
2   Ground water systems using water with high mineral content may face problems with
3 fouling because they do not typically have filtration installed. Systems using aeration to remove
4 radon may encounter problems with the oxidation and precipitation of iron and manganese.
5
6   Recommendations for Addressing this Issue
7
8   If the raw water is high in iron, manganese, or DOC, placing the UV reactor after the
9 filters will often alleviate the problem. If filtration does not sufficiently reduce the
10 concentrations of these compounds, other measures such as pre-oxidation will need to be taken.
11 Systems will need to consider the impacts of pre-oxidation on DBP formation. If DBP formation
12 is a problem and pre-oxidation is desired, alternative oxidants such as potassium permanganate
13 can be considered.
14
15   Systems that already use ozone for taste and odor control may also find it useful for
16 controlling UV absorbing compounds, if bromate formation can be kept under the Stage 1
17 D/DBPR MCL (see Section 5.2.2). Systems that cannot pre-oxidize may be able to achieve
18 higher removal of UV absorbing compounds by optimizing their coagulant dose. They should be
19 careful, however, to ensure their coagulant dose is truly optimized, since some coagulants can
20 also absorb UV light if they pass through the filters.
21
22   Placing the UV unit after the filter and ensuring proper filter operation should eliminate
23 significant concentrations of coagulants or polymers. Ozone, if used for taste and odor control,
24 will generally be added before the filters and will not enter the UV reactor. If this is not the case
25 and an ozone residual is present in the water before it enters the UV unit, the ozone should be
26 quenched. Ozone can be quenched by air stripping in the last chamber of the ozone contactor, or
27 using a reducing agent such as hydrogen peroxide. Some studies suggest, however, that ozone
28 quenching using hydrogen peroxide can be slow in low-alkalinity water (National Research
29 Council, 2000). The ozone residual should not be quenched with thiosulfate as it also absorbs
30 UV.

31   Chlorine dioxide should be added after the UV reactor. See Section 5.4 for further details
32 on chlorine dioxide use. There are no known effects of passing water with chlorine or
33 chloramine residual through UV reactors. If corrosion inhibitors that contain UV absorbing
34 compounds are used, they should be added after water has passed through the UV reactor.
35
36   Automatic wiper blades for the UV sleeves and/or more frequent manual cleanings may
37 be necessary to remove fouling caused by a variety of compounds that also absorb light. Ground
38 water systems may be able to handle the problem of mineral deposits by increasing cleaning
39 frequency of the lamp sleeves if concentrations are not too high and precipitated metals are not
40 released into the distribution system. Otherwise, systems may need to install cartridge filters
.

.

1   before the UV reactor. In such a system a cartridge filter can also help screen out debris that
2   could cause lamp breakage.
3
4   *Lamp Breakage*
5
6   Hydraulic upsets such as water hammer or debris can affect the delivered dose and even
7   break lamp sleeves. This can result in insufficient inactivation and the possibility of pathogens
8   passing into the distribution system where they can potentially cause public health problems.
9
10   Recommendations for Addressing this Issue
11
12   The UV reactor should have an automatic shut down. A written containment and cleanup
13   procedure should also be in place to prevent mercury from broken lamps from entering the
14   distribution system. Placing the UV unit after the filter will minimize the potential for lamp
15   breakage from debris. To eliminate hydraulic disturbances, the reactor should have flow control
16   valves before and after it, and should be sufficiently downstream of any hydraulic disturbances
17   such as pumps.
18
19   *Virus Inactivation*
20
22   While UV disinfection is highly
24   effective against protozoa such as
26   *Cryptosporidium*, it is less effective against
28   viruses. The LT2ESWTR requires that
30   systems considering substituting current
32   chlorination with UV disinfection have to
34   benchmark with respect to viruses,
35   *Giardia,* and *Cryptosporidium* and consult with the state to be sure that sufficient inactivation is
36   maintained.

> **While UV disinfection is highly effective against protozoa such as *Cryptosporidium* oocysts, it is less effective against viruses.**

37
38   Exhibit 5.3 shows the ratio of CT values required for inactivation of *Cryptosporidium* and
39   viruses for chlorine dioxide, ozone, and UV. CT is the product of concentration, or intensity in
40   the case of UV, and the exposure time required to achieve a certain level of inactivation. The
41   ratios show the relative strengths and weaknesses of the disinfectants in inactivating
42   *Cryptosporidium* oocysts versus viruses.
43
44

.

1 **Exhibit 5.3 Ratio of CT values for Inactivation of Viruses and *Cryptosporidium* at**
2 **10°C**
3

	Ratio of Virus Inactivation to Cryptosporidium Inactivation	
Disinfectant	Ratio of 2-log virus inactivation (99.0%) Ct to 0.5-log Cryptosporidium inactivation Ct (68.4%)	Ratio of 4-log virus inactivation Ct (99.99%) to 3.0-log Cryptosporidium inactivation Ct (99.9%)
Chlorine Dioxide	0.03	0.03
Ozone	0.10	0.03
UV[1]	17.2	15.5

4 [1] UV doses are in mJ/cm^2 and are calculated using safety factors based on the use of low pressure mercury lamps.
5 They may vary depending on the reactor validation method see the *Ultraviolet Disinfection Guidance Manual* (USEPA
6 2003b) for details.
7

8   To receive credit for disinfection with UV light, the proposed LT2ESWTR (40 CFR 141,
9 Subpart W, Appendix D) requires utilities to demonstrate through validation testing that the UV
10 reactor can deliver the required UV dose. The testing must determine a range of operating
11 conditions that can be monitored by the system and under which the reactor delivers the required
12 UV dose. EPA developed UV dose requirements for *Cryptosporidium*, *Giardia*, and viruses that
13 are used during the validation process (see *UV Disinfection Guidance Manual* (USEPA 2003b)
14 for dose requirements and application during validation).
15

16   Recommendations for Addressing this Issue
17

18   Systems that adopt UV disinfection will need to take special care to ensure that the virus
19 benchmark is achieved. The state should be consulted throughout the planning process to ensure
20 that inactivation requirements can be met to achieve the necessary credit. Some viruses, in
21 particular adenoviruses, are very resistant to UV light. Data show that a dose of 186 mJ/cm^2 is
22 required to achieve 4-log inactivation of adenovirus (68 FR 47713, August 11, 2003).
23

24   Readers should refer to the *Ultraviolet Disinfection Guidance Manual* (USEPA 2003b)
25 for more information on proper procedures for challenge testing. Testing of full-scale UV
26 reactors is necessary to ensure disinfection performance and a consistent level of public health
27 protection. However, EPA is not aware of an available challenge microorganism that allows for
28 full-scale testing of UV reactors to demonstrate 4-log inactivation of adenovirus. Methodologies

.

1   for challenge testing at doses necessary to inactivate UV resistant viruses may be developed in
2   the future.
3   Until then, UV technology should be used in a series configuration or in combination
4   with other inactivation or removal technologies to provide a total 4-log treatment of viruses.
5   This option uses a second disinfectant to achieve virus inactivation and uses UV only for
6   *Cryptosporidium* and *Giardia* inactivation. The second disinfectant could be added after the UV
7   reactor to maintain a residual in the distribution system or it could be added prior to the UV
8   reactor where it could also serve as a preoxidant. Surface water systems will need to add
9   secondary disinfection anyway to comply with the entry point and distribution system residual
10   requirements of the SWTR. If a second disinfectant is used also for additional virus inactivation,
11   it must achieve the required inactivation before the first customer. Chlorine will provide virus
12   inactivation with a relatively low dose, but may produce DBPs and could create problems with
13   Stage 2 DBPR requirements. Chloramines will have less DBP formation but will require
14   significantly longer contact time in the clearwell to ensure appropriate inactivation before the
15   first customer. See Section 5.1.1 for more details on the use of chloramines.
16
17   If pre-oxidation is practiced, chlorine, ozone, or chlorine dioxide can be used. Chlorine
18   may not be an attractive solution because the production of DBPs. Ozone will likely be cost
19   prohibitive unless it is already installed; in which case it would have numerous advantages.
20
21   *UV Does Not Provide a Residual*
22
23   UV disinfection, because it is not a chemical disinfectant, does not leave a residual and
24   cannot be used to meet SWTR requirements regarding entry point and distribution system
25   residuals.
26
27   <u>Recommendations for Addressing this Issue</u>
28
29   Chlorine (Chapter 3), chloramines (Section 5.1), or chlorine dioxide (Section 5.4) can be
30   used to maintain a residual disinfectant. Chlorine is effective against viruses and bacteria but can
31   cause significant problems with Stage 2 DBPR compliance, especially in portions of the
32   distribution system with long residence times where organic carbon is present. Chlorine dioxide
33   is effective against *Cryptosporidium* and *Giardia* but its residual does not last as long, and can
34   form chlorite, a regulated DBP. Chloramines as a residual disinfectant after UV disinfection
35   have the potential to provide adequate distribution system residual and very low DBPs.
36   Problems with chloramines include potential issues with nitrification, potential corrosion
37   problems, and taste and odor issues if the chlorine:ammonia ratio is not maintained properly.
38
39   *Power Outages Disrupt Disinfection*
40

.

.

1   UV disinfection relies on a power supply to deliver disinfection. If power is interrupted,
2   the UV reactor loses all disinfection capability. Even fluctuations in power can cause a UV
3   system to operate outside of validated ranges. After power is restored, UV reactors also require a
4   warm-up time before they can operate on specification. A major power disruption can cause the
5   system to be out of compliance with microbial inactivation requirements.
6
7   Recommendations for Addressing this Issue
8
9   To be prepared for power outages, the UV reactor should be equipped with flow
10   diversion or automatic shut-off valves that prohibit untreated water from entering the distribution
11   system. Units should be alarmed to alert operators if any power failures occur. The backup
12   power system for the plant should be designed to provide power to the UV reactor in the case of
13   a power failure. Backup power supplies such as a Universal Power Supply (UPS) or a second
14   power leg may alleviate some of these problems. Systems should be configured so that sufficient
15   "warm-up" time is allowed for the UV lamps before water passes through and on to customers.
16
17   *Requires Additional Training*
18
19   Operation of the system and understanding parameters that must be monitored to ensure
20   safe and efficient disinfection are very different than operation of a chemical disinfection system.
21   Therefore, training will be needed so operators understand the new equipment and operate it
22   correctly.
23
24   Recommendations for Addressing this Issue
25
26   Equipment vendors and state officials should be contacted early in the process, regarding
27   the appropriate training for UV disinfection. Systems considering UV should check with their
28   state to determine whether there are water quality monitoring requirements as well. Systems
29   may also want to perform pilot tests to be sure the water will not produce excessive fouling of
30   lamp sleeves and bench scale UV absorbance tests to determine how much UV will be absorbed
31   in the germicidal range of 200 to 300 nanometers. If such tests are not economically feasible the
32   likelihood of fouling may be able to be determined by measuring parameters such as the
33   Langelier Saturation Index (LSI).
34
35   UV reactors will also require keeping additional replacement parts in stock. Parts that
36   will need to be replaced periodically include lamp bulbs, lamp sleeves, reactor seals, and sleeve
37   seals. Wiper blades and/or cleaning fluid will be needed as well, depending on the method
38   chosen for cleaning lamp sleeves. Systems should consult the equipment manufacturer, their
39   state, and other experienced utilities for a list of replacement parts to keep in stock.
40

.

.

1   ### 5.3.3   Recommendations for Gathering More Information
2
3   *Read Case Study*
4
5   ***Case Study # 12 – Ultraviolet Disinfection*** on page B-77 in Appendix B describes a
6   surface water system with a 16 MGD plant that converted from chlorine to UV treatment to
7   achieve its CT. The system uses a large river as its source and needed to reduce its DBPs. In
8   anticipation of LT2ESWTR, it opted for UV because of the additional benefit that UV
9   inactivates *Cryptosporidium*. One of the biggest challenges the system faced with the transition
10 was providing the training needed to operate and maintain the UV system. This case study
11 describes how the system addressed this and other issues it encountered as one of the first surface
12 water systems of its size to switch over to UV.
13
14 *See Additional References*
15
16   Readers can turn to Chapter 7 for further references on this topic. Section 7.1.1 includes
17 general references on water treatment, section 7.1.2 includes references on controlling DBP
18 formation, and section 7.1.14 includes references on UV disinfection.
19
20 *Consider Additional Monitoring*
21
22   The following are some suggestions for additional monitoring that may benefit water
23 systems implementing UV disinfection. The purpose of these monitoring suggestions is
24 specifically to address and prevent potential simultaneous compliance issues. Monitoring should
25 be done before the design process to allow for proper design of the system. Water system
26 managers should discuss process control monitoring with the manufacturer of their UV units,
27 their engineer, and other experienced utilities.
28
29   ✓ Periodic measurements of inorganic and organic chemicals, as applicable, in the water
30   entering the UV unit. Tracking their concentrations will help a system make sure levels
31   are low enough and will not interfere with UV disinfection. Some compounds with this
32   potential are:
33
34   • Iron
35   • Manganese
36   • Calcium
37   • Magnesium
38   • Aluminum
39   • Dissolved Organic Carbon
40   • Ozone
41

.

1   *Consider Other Tools*
2
3   In addition to water quality monitoring, there are additional tools listed in Chapter 6 that
4   could help systems evaluate and improve their current water system in relation to the compliance
5   issues they may face when modifying their treatment operations. Examples of tools that can be
6   used when UV is used for Stage 2 DBPR compliance include:
7
8   •   The EPA "Draft Ultraviolet Disinfection Guidance Manual" (U.S. EPA 2003b) which
9   provides guidance on the validation, selection, design, and operation of UV
10   disinfection systems as well as general guidelines for UV disinfection pilot testing;
11   •   The AwwaRF report "Integrating UV Disinfection Into Existing Water Treatment
12   Plants" (Cotton et al. 2006) which provides user-friendly web tools that will assist
13   utilities in assessing important disinfection decisions and UV implementation issues;
14   •   The AwwaRF report "Full Scale Implementation of UV in Groundwater Disinfection
15   Systems" (Malley 2001) which provides specific guidance for the selection, design,
16   and operation of UV systems;
17   •   Various cost estimation models that can be used to estimate the cost of implementing
18   a new UV facility.
19
20   Readers are encouraged to read through Chapter 6 before making any final compliance decisions.
21

5.4   Chlorine Dioxide

Chlorine dioxide is an alternative chemical disinfectant that can be used to lower DBP production while maintaining adequate levels of inactivation. Because it is unstable, it is generated onsite using chlorine dioxide generators.

Chlorine dioxide has gained popularity because it produces relatively few THMs and HAAs. It is also very effective against bacteria, viruses, and *Giardia* cysts, and can provide some inactivation of *Cryptosporidium* oocysts at higher temperatures. The main drawback of chlorine dioxide is that the chlorine dioxide MRDL of 0.8 mg/L combined with an MCL of 1.0 mg/L for chlorite, the main byproduct of chlorine dioxide, limit the dose that can be applied. In addition, low water temperatures can make it more difficult to use chlorine dioxide.

5.4.1   Advantages of Chlorine Dioxide

Chlorine dioxide's advantages include:

- **Effectively inactivates bacteria, virus, and *Giardia* cysts; can achieve some *Cryptosporidium* oocyst inactivation**

- **Less TTHM and HAA5 formation than chlorine**

- **Effective oxidant for the control of iron, manganese, hydrogen sulfide, and phenolic compounds**

- **Not significantly affected by pH values between 6 and 9**

Effective Disinfectant

Chlorine dioxide is a strong oxidant and can therefore effectively inactivate a wide range of microbes. Exhibit 5.4 compares the required CT values of chlorine dioxide with those of chlorine and ozone. Chlorine dioxide is slightly less effective than chlorine against viruses and bacteria, but is more effective against *Giardia* and *Cryptosporidium.*

1   **Exhibit 5.4 CT Values for Inactivation of Microorganisms by Chlorine Dioxide**
2   **Compared with Other Chemical Disinfectants at 10°C and pH 6-9 (in mg-min/L)**
3

Microbe	Inactivation Level	Chlorine Dioxide	Chlorine[1]	Ozone
Viruses	2-log (99.0%)	4.2	3	0.5
Viruses	4-log (99.99%)	25.1	6	1.0
Giardia	0.5-log (68.4%)	4	17	0.23
Giardia	3.0-log (99.9%)	23	104	1.43
Cryptosporidium	0.5-log (68.4%)	138	N/A	4.9
Cryptosporidium	3.0-log (99.9%)	830	N/A	30

4   Source: USEPA 2003a
5   N/A - not applicable. Chlorine is ineffective against *Cryptosporidium*.
6   1 - Chlorine CT values for pH 7
7
8
9   Chlorine dioxide can achieve some inactivation of *Cryptosporidium* oocysts. Required
10   CT levels for *Cryptosporidium* inactivation are relatively high though, so achieving more than a
11   half log inactivation is unlikely given restrictions on dose. See the following section for a further
12   discussion of dose restrictions. Chlorine dioxide can, however, be a relatively low cost
13   alternative for systems that require a 0.5 log *Cryptosporidium* inactivation to comply with the
14   LT2ESWTR.
15
16   *Less TTHM and HAA5 Formation*
17
18   Chlorine dioxide provides a good alternative to chlorine for systems that wish to lower
19   the formation of TTHM or HAA5. Pure chlorine dioxide does not form significant amounts of
20   TTHM or HAA5. Most chlorine dioxide generators do produce some chlorine as a byproduct,
21   however, so some TTHM and HAA5 will still be formed. The DBP of greater concern when
22   chlorine dioxide is used is chlorite, which has a 1.0 mg/L MCL. See the discussion in the
23   following section for more information on minimizing chlorite formation. Systems
24   contemplating changing to chlorine dioxide will be required to perform a disinfection benchmark
25   for viruses, *Giardia*, and *Cryptosporidium* and consult with the state to ensure adequate
26   disinfection levels are maintained.
27
28   *Effective Oxidant*
29
30   Another advantage to chlorine dioxide is that it is a strong oxidant. It can effectively
31   oxidize many compounds including iron and taste and odor compounds. Under the right pH

.

1   conditions it can oxidize arsenic, which is often the first step in arsenic treatment. Oxidation of
2   arsenic does not alone result in the removal of arsenic from water, but it enhances its removal
3   during additional treatment. Systems that were previously using chlorine to pre-oxidize these
4   chemicals may be able to achieve the same goals using chlorine dioxide, and simultaneously
5   reduce TTHM and HAA5 to comply with the Stage 2 DBPR.
6
7   *Not Significantly Affected by pH*
8
9   The efficiency of chlorine dioxide does not vary significantly in the pH range of 6 to 9.
10   This benefits systems trying to meet benchmarks since the CT achieved will not vary with pH.
11   This also gives systems more flexibility with their treatment. They can adjust pH values to
12   improve coagulation, reduce corrosion, or reduce DBP formation without concern for losing
13   disinfection efficiency. It is possible, however, that some plants using enhanced coagulation or
14   enhanced softening may fall outside the pH range of 6 to 9. See the following section for further
15   discussion of these cases.
16
17   **5.4.2   Potential Operational and Simultaneous Compliance Issues Associated with**
18   **Chlorine Dioxide Use**
19
20   Potential issues with using chlorine dioxide include the following:
21
22
23   • **Forms chlorite, a regulated DBP**
24
25   • **Reduced effectiveness at low temperature**
26
27   • **Chlorine dioxide MRDL of 0.8 mg/L**
28
29   • **Can form brominated DBPs**
30
31   • **Degrades when exposed to UV light**
32
33   • **Residual dissipates quickly**
34
35   • **Potential odor problems**
37
38   • **Requires additional training and safety concerns**
39
40   This section addresses these issues and provides recommendations for addressing them.
41
42   *Chlorite Formation*

.

.

1
2   One of the biggest disadvantages of using chlorine dioxide as a disinfectant is that it
3   forms chlorite. The MCL for chlorite was set at 1.0 mg/L by the Stage 1 D/DBPR. Systems
4   using chlorine dioxide must monitor daily at the entrance to the distribution system for chlorite.
5   They must also collect 3 chlorite samples per month in the distribution system. As much as 70
6   percent of the chlorine dioxide added to water can break down to form chlorite. This limits the
7   dose of chlorine dioxide that can be used and therefore the amount of inactivation that can be
8   achieved. This especially limits *Cryptosporidium* inactivation, since the required CT values for
9   *Cryptosporidium* are much higher than for other microbes.
10
11   High oxidant demand and high pH also lead to higher chlorite production. If there is
12   substantial oxidant demand in a system's water due to natural organic matter (NOM) or reduced
13   metals, the oxidant demand will consume the chlorine dioxide and form chlorite, but the
14   chlorine dioxide consumed in this way will not achieve any disinfection. Systems then have to
15   add higher chlorine dioxide doses to achieve sufficient inactivation, and as a result generate
16   higher chlorite concentrations.
18
20   Water pH values above 9 also lead to
22   increased production of chlorite. Systems
24   with high pH as a result of enhanced
26   softening or corrosion control may have
28   trouble complying with the chlorite MCL.

> **One of the biggest disadvantages of using chlorine dioxide as a disinfectant is that it forms chlorite.**

29
30   Recommendations for Addressing this Issue
31
32   There are several ways to minimize chlorite concentrations. Adding chlorine dioxide
33   after the filters, after the oxidant demand has been reduced, can result in lower chlorite
34   concentrations. In order to comply with the LT1ESWTR or IESWTR, systems must benchmark
35   and check with the state before moving the point of disinfection. Systems using chlorine dioxide
36   as a pre-oxidant may also reduce the water's oxidant demand by using pre-sedimentation before
37   chlorine dioxide is injected.
38
39   Systems that increase pH during treatment should try to do so after the chlorine dioxide
40   contact chamber. They may want to reduce the treated water's pH to below 9 before adding the
41   chlorine dioxide.
42
43   Even if systems control pH and have no oxidant demand outside of microbial
44   inactivation, 50 to 70 percent of the chlorine dioxide consumed will form chlorite. This puts an
45   effective limit on the dose that can be applied. Most systems will not be able to apply chlorine
46   dioxide doses of greater than 1.2 mg/L without risking exceeding the chlorite MCL. Systems
47   that cannot achieve the desired inactivation with a chlorine dioxide dose of less than 1.2 mg/L

.

.

1   may want to consider using another disinfectant in addition to chlorine dioxide to achieve the
2   necessary inactivation. Another possibility is that the chlorite could be reduced using a reductant
3   such as thiosulfate, which would then allow the use of higher chlorine dioxide doses.
4
5   *Reduced Effectiveness at Low Temperatures*
6
7   The disinfection effectiveness of chlorine dioxide is temperature sensitive. It is much
8   less effective at colder temperatures. Exhibit 5.5 shows the temperature sensitivity of chlorine
9   dioxide in terms of *Cryptosporidium* oocyst inactivation.
10
11
12   **Exhibit 5.5 Effect of Temperature on the CT Required for *Cryptosporidium***
13   **Inactivation by Chlorine Dioxide**
14

Temperature (^{o}C)	CT (in mg-min/L) for 0.5-log inactivation (69.3%)	CT (in mg-min/L) for 2.0-log inactivation
1	305	1275
10	138	553
25	38	150

15   Source: USEPA 2003a
16
17
18   As a result of this temperature dependence, systems in cold weather climates may not be
19   able to use chlorine dioxide to meet the *Cryptosporidium* inactivation requirements of the
20   LT2ESWTR.
21
22   Recommendations for Addressing this Issue
23
24   Systems may be able to achieve some inactivation by increasing the chlorine dioxide
25   dose and then using a reducing agent such as thiosulfate to reduce the chlorite to chloride, or by
26   using a second disinfectant. In general though, systems that regularly experience near freezing
27   temperatures should probably investigate other disinfection techniques.
28
29   *Chlorine Dioxide MRDL*
30
31   Chlorine dioxide itself can have health effects at elevated levels. Therefore it has an
32   MRDL of 0.8 mg/L. Systems using chlorine dioxide will have to monitor the chlorine dioxide
33   residual at the entry point to the distribution system, before the first customer. Systems using
34   chlorine dioxide may have to limit their doses to prevent exceeding the MRDL.
.

.

1
2   Chlorite can react with excess chlorine in the distribution system to reform chlorine
3   dioxide. Some systems may opt to boost with chlorine to maintain a residual in the distribution
4   system. Systems that use chlorine dioxide and then boost with chlorine in the distribution system
5   are required by the Stage 1 D/DBPR to monitor the chlorine dioxide residual in the distribution
6   system. If doses are high enough, systems could exceed either the chlorine dioxide MRDL or the
7   chlorite MCL. Reformed chlorine dioxide can also volatilize at consumer's taps and react with
8   volatile organics to cause odor problems.
9
10   If a system intentionally re-forms chlorine dioxide by boosting with chlorine in the
11 distribution system, it is required by the Stage 1 D/DBPR to monitor both chlorite and chlorine
12 dioxide in the distribution system.
13
14   Recommendations for Addressing this Issue
15
16   If chlorine dioxide doses are kept below 1 mg/L, exceeding the MRDL should not be a
17 problem. If reformation of chlorine dioxide is not desired, chloramines can be used in the
18 distribution system instead of chlorine. If doses much higher than 1.2 mg/L are used, a reducing
19 agent can be added to the water before it enters the distribution system to reduce any chlorine
20 dioxide residual or chlorite to chloride. This will also prevent formation of chlorine dioxide in
21 the system by booster addition of chlorine.
22
23   If a system intentionally re-forms chlorine dioxide by boosting with chlorine in the
24 distribution system, the system should conduct bench scale tests to determine the correct chlorine
25 dose to add to achieve an adequate residual without exceeding either the chlorine dioxide MRDL
26 or the chlorite MCL. Systems should take into consideration the expected residence time in the
27 distribution system. Although some small systems in Canada have maintained adequate
28 residuals using doses of 0.4 to 0.6 mg/L of chlorine dioxide, other larger systems have found loss
29 of residual at the end of the distribution system using similar doses (Volk et al. 2002).
30
31 *Can Form Brominated DBPs*
32
33   Chlorine dioxide can oxidize bromide ions to bromine. The bromine can then react with
34 organic matter to form brominated DBPs. Systems with high bromide concentrations that are
35 near the Stage 2 DBPR limits for TTHM or HAA5 will need to take this into account.
36
37   Recommendations for Addressing this Issue
38
39   Systems with high bromide concentrations that are near the Stage 2 DBPR limits for
40 TTHM or HAA5 can lower DBP formation by adding chlorine dioxide after the filters, where
41 organic concentrations are lower. Enhancing coagulation will also lower the amount of organic

.

.

1   matter available to react with chlorine dioxide after the filters. Systems that use chlorine
2   dioxide for pre-oxidation may be able to achieve some organic removal by using pre-
3   sedimentation basins. Systems with very high bromide can remove it using ion exchange
4   columns, but this is rarely an economical solution.
5
6   *Degrades When Exposed to UV Light*
7
8   Chlorine dioxide is sensitive to UV light and will degrade to form chlorate when exposed
9   to UV light. This will reduce chlorine dioxide residuals and therefore lower inactivation.
10
11   <u>Recommendations for Addressing this Issue</u>
12
13   Systems using chlorine dioxide can prevent degradation by light by covering the contact
14   basin. If a building or hard cover are not cost effective or require too much space, floating
15   covers can shield the chlorine dioxide from the UV light. The manufacturer should be consulted
16   in selecting the cover material to be sure it is compatible with chlorine dioxide.
17
18   Systems using chlorine dioxide and UV disinfection together should add the chlorine
19   dioxide either after the UV reactor or sufficiently ahead of the reactor that there is no residual
20   entering the reactor. Systems should not use the residence time of UV reactors to receive contact
21   time credit for chlorine dioxide added earlier in the treatment process.
22
23   *Residual Dissipates Quickly*
24
25   Chlorine dioxide is highly reactive and will react with GAC and anthracite in filters.
26   Chloride formed by the reaction of chlorine dioxide and GAC can also adsorb to the GAC and
27   cause weaker binding elements to be released. See Section 4.1 for more information on GAC
28   use. Chlorine dioxide is also volatile and can be lost in rapid mix basins or other unit processes
29   that have high turbulence and are exposed to the atmosphere.
30
31   <u>Recommendations for Addressing this Issue</u>
32
33   Filters should not be used to achieve contact time for chlorine dioxide. Rapid mix basins
34   can be used for contact time, but may require higher doses to achieve the same inactivation level.
35   Adding the chlorine dioxide after filtration will avoid any unnecessary residual loss and will
36   maximize the chlorine dioxide dose that is available for disinfection.
37
38   Systems adding chlorine dioxide as a pre-oxidant can add the chlorine dioxide in the
39   coagulation basins. Systems with low alkalinity may see a slight rise in pH after chlorine
40   dioxide addition.
41

.

.

1 *Potential Formation of Odor Causing Compounds*
2
3   Chlorine dioxide residuals in customers tap water has been found to volatilize at the tap
4 and to react with volatile organic compounds (VOCs) in customer's houses forming compounds
5 with particularly bad kerosene-type odor (Hoehn et al. 1990). It can also sometimes give a
6 strong chlorinous odor.
7
8   <u>Recommendations for Addressing this Issue</u>
9
10   The appearance of odors in customer's homes is difficult to predict and therefore prevent.
11 Utilities can keep good customer complaint records and provide public education on what to do
12 if such odors occur. Suggestions for dealing with odors in the household include improving
13 ventilation and using carbon filters to remove the chlorine dioxide residual.
14
15 *Additional Training Needed, Safety Concerns*
16
17   The nature of chlorine dioxide and the chemicals used to generate it requires additional
18 training and safety precautions to ensure safe operation of the treatment plant. Sodium chlorite is
19 often used to generate chlorine dioxide. When acidified, it can produce large amounts of
20 gaseous chlorine dioxide. Chlorine dioxide at concentrations greater than 0.1 ppm is toxic and
21 can cause shortness of breath, coughing, respiratory distress, and pulmonary edema. Gaseous
22 chlorine dioxide concentrations greater than 10 percent can be explosive. Sodium chlorite fires
23 burn very hot and produce oxygen as a byproduct.
24
25   <u>Recommendations for Addressing this Issue</u>
26
27   Systems should contact their chlorine dioxide equipment manufacturer to schedule any
28 necessary training. Sodium chlorite should be stored away from other chemicals, especially
29 acids and reducing agents. It should be stored in an area made of fire resistant materials such as
30 concrete. The area should be equipped with monitoring equipment to detect chlorine dioxide and
31 other chlorine components in the atmosphere. Proper ventilation and scrubbers should be
32 provided in the area. A special plan should be developed to respond to leaks or fires in the area
33 and the necessary equipment to implement the plan, including respirators, should be stored and
34 accessible outside the sodium chlorite storage area. If more than 1,000 pounds are stored on site
35 the plan must be formalized into a Risk Management Plan (RMP) and OSHA's specific
36 requirements for storage of chlorine dioxide must be satisfied.
37
38 **5.4.3   Recommendations for Gathering More Information**
39
40 *Read Case Studies*
41

.

.

1   Two case studies provided in Appendix B describe systems that switched to chlorine
2   dioxide to reduce DBPs in their finished water and the simultaneous compliance challenges they
3   encountered when making the switch.
4
5   *Case Study #13 - Chlorine Dioxide for Primary Disinfection and Chloramines for*
6   *Secondary Disinfection* on page B-81 describes a surface water treatment plant in a wholesale
7   system serving seven municipalities and approximately 92,000 people. The treatment plant
8   switched from chlorine to chlorine dioxide as its primary disinfectant and from chlorine to
9   chloramines for residual disinfection. In addition, the system uses chlorine dioxide intermittently
10 as a pre-oxidant in its raw water. Among the challenges the system has encountered is being
11 able to achieve sufficient *Cryptosporidium* inactivation to be granted LT2ESWTR credit and still
12 comply with the Stage 1 DBPR's chlorite MRDL.
13
14   *Case Study #14 – Chlorine Dioxide for Primary Disinfection and Chloramines for*
15 *Secondary Disinfection* on page B-89 describes a surface water system serving fewer than
16 10,000 people per day that also switched from chlorine to chlorine dioxide for CT and to
17 chloramines for residual disinfection. The system, which is challenged by zebra mussels
18 clogging its intake, found chlorine dioxide pretreatment works well as a replacement for the
19 potassium permanganate previously used. It also adopted a monitoring program to watch for
20 nitrification in its extensive distribution system.
21
22 *See Additional References*
23
24   Readers can turn to Chapter 7 for further references on this topic. Section 7.1.1 contains
25 general references on water treatment, section 7.1.2 contains references on controlling DBP
26 formation, and section 7.1.15 contains references on chlorine dioxide.
27
28 *Consider Additional Monitoring*
29
30   The following are some suggestions for additional monitoring that may benefit water
31 systems using chlorine dioxide. The purpose of these monitoring suggestions is specifically to
32 address and prevent potential simultaneous compliance issues. Water system managers should
33 discuss process control monitoring with the manufacturer of their chlorine dioxide equipment or
34 their engineer.
35
36 ✓ If a system uses chlorine dioxide and has any kind of uncovered storage, chlorine dioxide
37   residuals should be measured after the open storage to ensure that a sufficient chlorine
38   dioxide residual has been maintained.
39
40 ✓ Customer complaints can be monitored to determine if chlorine dioxide residuals are
41   causing problems.
.

.

1
2
3   *Consider Other Tools*
4
5   In addition to water quality monitoring, there are additional tools available in Chapter 6
6   to help systems evaluate and improve their current water system in relation to the compliance
7   issues they may face when modifying their treatment operations. Examples of tools that can be
8   used when chlorine dioxide is used for Stage 2 DBPR compliance include:
9
10   •   The "Guidance Manual for Monitoring Distribution System Water Quality" (Kirmeyer
11   2002) which can be used to assist water utilities in implementing a distribution system
12   water quality data collection and analysis program, especially for chlorite and chlorine
13   dioxide residuals;
14   •   The AwwaRF report "Internal Corrosion of Water Distribution System" (AWWARF and
15   DVGW-Technologiezentrum Wasser 1996) which provides bench-scale and pilot testing
16   protocols that can be used to evaluate changes in corrosion potential due to the switch to
17   chlorine dioxide;
18   •   The Standard Method 2350 (Oxidant Demand/Requirement) (APHA 1998) that provides
19   step-by-step instruction for the determination of chlorine dioxide demand;
20   •   The AwwaRF report "Water Utility Self-Assessment for the Management of Aesthetic
21   Issues" (McGuire et al. 2004) which can be used to guide utilities in conducting self-
22   assessment on their taste and odor issues caused by ozonation and to identify subsequent
23   control strategies; and
24   •   The AwwaRF report "Tools and Methods to Effectively Measure Customer Perceptions"
25   (Colbourne 2001) which describes tools that allow utilities to measure customer
26   perceptions and changes in their opinions toward the use of chlorine dioxide.
27
28   Readers are encouraged to read through Chapter 6 before making any final compliance decisions.
29

.

1   **5.5   Primary and Residual Disinfectant Use**
2
3   Different combinations of primary and residual (i.e., secondary) disinfectants can present
4   different issues and concerns. For example, when ozone is used as the primary disinfectant
5   followed by chloramines as the residual disinfectant, water systems should be aware that
6   increased AOC concentrations resulting from ozonation may increase the likelihood of problems
7   with nitrification in the distribution system. On the other hand, the chlorite ion produced by
8   chlorine dioxide during primary disinfection may actually be effective at inactivating ammonia-
9   oxidizing bacteria and, as a result, reduce nitrification in the distribution system.
10
11   This section follows a different format than many of the previous sections in this
12   guidance manual. Exhibit 5.6 provides a summary table of the potential benefits and
13   simultaneous compliance issues of the various combinations of primary and residual
14   disinfectants. Brief paragraphs then follow the table, which describe noteworthy issues related to
15   different disinfectant combinations.
16
17

Exhibit 5.6 Summary of Potential Benefits and Adverse Effects Associated with Different Combinations of Primary and Residual Disinfectants

Disinfection Switch (primary/residual, from ➜to)	Potential Benefits	Potential Adverse Effects	Drinking Water Regulation(s) Impacted
Chlorine/Chlorine ➜ Chlorine/Chloramines	• improved ability to maintain a disinfectant residual • lower TTHM and HAA5 • possible improved biofilm control • improved taste and odor • *Giardia* and virus inactivation	• excess ammonia can cause nitrification • possible elevated nitrite/nitrate levels • low *Cryptosporidium* inactivation • possible corrosion concerns • concerns for dialysis patients, fish owners, and other industrial customers	• Stage 2 DBPR • SWTR • TCR • LCR • Stage 1 DBPR • IESWTR • LT1ESWTR
Chlorine/Chlorine ➜ Ozone/Chlorine	• Lower TTHM and HAA5 • *Cryptosporidium* inactivation • better taste and odor control • *Giardia* and virus inactivation	• Bromate MCL concerns • additional bromate monitoring required • may increase brominated DBPs • increased AOC may enhance biofilm growth	• Stage 2 DBPR • Stage 1 D/DBPR • LT2ESWTR • TCR
Chlorine/Chlorine ➜ Ozone/Chloramines	• Lower TTHM and HAA5 • *Cryptosporidium* inactivation • improved ability to maintain disinfectant residual • may improve taste and odor • *Giardia* and virus inactivation	• nitrification may increase • possible elevated nitrite/nitrate levels • possible corrosion concerns • bromate MCL concerns • additional bromate monitoring required • increased AOC may enhance biofilm growth • concerns for dialysis patients, fish owners, and other industrial customers	• Stage 2 DBPR • Stage 1 D/DBPR • SWTR • LT2ESWTR • TCR • LCR
Chlorine/Chlorine ➜ Chlorine Dioxide/ Chlorine Dioxide	• lower TTHM and HAA5 • *Cryptosporidium* inactivation • *Giardia* and virus inactivation	• additional chlorine dioxide and chlorite monitoring required • chlorite MCL concerns • chlorine dioxide MRDL concerns • can be difficult to maintain a chlorine dioxide residual • safety concerns	• Stage 2 DBPR • Stage 1 DBPR • LT2ESWTR • SWTR

Chlorine/Chloramines ➔ Chlorine Dioxide/ Chloramines	• Lower TTHM and HAA5 • *Cryptosporidium* inactivation • *Giardia* and virus inactivation • can control iron and manganese • chlorite from chlorine dioxide may control nitrification	• additional chlorine dioxide and chlorite monitoring required • chlorite MCL concerns	• Stage 2 DBPR • Stage 1 DBPR • LT2ESWTR • LCR
Chlorine/Chloramines ➔ Ozone/Chloramines	• Lower TTHM and HAA5 • *Cryptosporidium* inactivation • improved taste and odor control • *Giardia* and virus inactivation	• increased AOC can encourage nitrification and biofilm growth • additional bromate monitoring required • ozone taste and odor issues • may create brominated DBPs	• Stage 2 DBPR • Stage 1 D/DBPR • LT2ESWTR • TCR • LCR
Ozone/Chlorine➔ Ozone/Chloramines	• Lower TTHM and HAA5 • improved ability to maintain a disinfectant residual • improved taste and odor control • *Giardia* and virus inactivation	• AOC may encourage nitrification • concerns for dialysis patients, fish owners, and other industrial customers • possible corrosion concerns	• Stage 2 DBPR • SWTR • TCR • LCR
Chlorine/Chlorine or Chlorine/Chloramines ➔ UV/Chlorine or UV/Chloramines	• Lower TTHM and HAA5 • *Cryptosporidium* inactivation • *Giardia* and virus inactivation	• UV less effective than chlorine at inactivating viruses • UV is not a pre-oxidant • less taste and odor control	• Stage 2 DBPR • SWTR • LT2ESWTR
Ozone/ Chlorine ➔ Ozone/ UV/Chlorine	• additional *Cryptosporidium* inactivation • good taste and odor control • *Giardia* and virus inactivation	• ozone can lower UV transmittance	• LT2ESWTR

1

1   **5.5.1   Noteworthy Issues About Disinfectant Combinations**
2
3   *Potential Drawback of Switching from Chlorine/ Chloramines to Ozone/ Chloramines*
4
5   Changing to ozone as a primary disinfectant while maintaining chloramines as a
6   secondary disinfectant may impact TCR compliance due to the action of ozone on natural
7   organic matter. Having already established distribution system practices for biofilm growth in
8   chloraminated distribution water, public water systems making this disinfection practice
9   modification should focus on the biological stability of their distribution system water.
10
11   In cases where the use of ozone as the primary disinfectant increases levels of AOC,
12   biological stability in the distribution system could be disrupted. AOC provides nutrient value
13   for cell metabolism. In a previously chloraminated system, control of nitrification may be
14   achieved using one or more of the techniques described in Section 5.1.2. However, the
15   additional nutrition provided by the increased AOC may require modification to the practices.
16   Alternatively, biological filtration can be used to effectively reduce nutrient levels. Biological
17   filtration can also reduce dissolved oxygen, which can lead to changes in redox chemistry in the
18   system and potentially change scale chemistry, affecting corrosion control treatment.
19
20   *Potential Benefit of Switching from Chlorine/ Chloramines or Ozone/ Chloramines to Chlorine*
21   *Dioxide/ Chloramines*
22
23   McGuire et al. (2006) provided field and laboratory evidence that the chlorite ion may be
24   effective at controlling nitrification in distribution systems. The study showed that even low
25   dosages of chlorite (0.1 mg/L) were effective at inactivating 3 to 4 logs of ammonia-oxidizing
26   bacteria over several hours. Field investigations at five water systems in Texas showed that the
27   presence of chlorite in the distribution systems resulted in less loss of chloramines and ammonia-
28   nitrogen.
29
30   **5.5.2   Recommendations for Gathering More Information**
31
32   *Read Case Study*
33
34   *Case Study #14 - Chlorine Dioxide for Primary Disinfection and Chloramines*
35   *for Residual Disinfection* on page B-89 in Appendix B provides an example of a small surface
36   water system that switched from chlorine for primary and residual disinfection to chlorine
37   dioxide for primary disinfection and chloramines for residual disinfection. The system pays
38   close attention to the potential for nitrification in its distribution system as a result of the
39   chloramines, and has developed a monitoring program and guidelines for action to prevent
40   nitrification episodes. Chlorite is one of the parameters tracked closely in the distribution
41   system. The system tries to take advantage of the possibility that chlorite may be toxic to
42   nitrifying bacteria.
43

1   *See Additional References*
2
3   Readers can refer to Chapter 7 for more references on this topic. Section 7.1.1 contains
4   references on general water treatment, section 7.1.2 contains references on controlling DBP
5   formation, Section 7.1.12 contains references on chloramines, Section 7.1.13 contains references
6   on ozone, Section 7.1.14 contains references on UV disinfection, and Section 7.1.15 contain
7   references on chlorine dioxide.
8
9   *Consider Tools*
10
11   There are additional tools available to help systems evaluate and improve their current
12   water system in relation to the compliance issues they may face when modifying their treatment
13   operations. Readers are encouraged to read through Chapter 6 before making any final
14   compliance decision.
15

1
2
3
4 <div style="border: 2px solid black; padding: 10px;">**6   Making Compliance Decisions**</div>
5
6
7
8   This Chapter covers:
9
10   11   6.1   Introduction
12   6.2   Issues to Consider When Making a Compliance Decision
13   6.3   Tools for Gathering Information
14
15   The information provided in this chapter is meant to help water system managers and
16   their regulators identify what issues should be considered before a change in treatment or
17   operations is made. It also describes tools available to help systems collect information that is
18   applicable and helpful for making their compliance decisions.
19
20   **6.1 Introduction**
21
22   To comply with the Stage 2 DBPR and LT2ESWTR, water systems will be making
23   changes to their treatment and operations ranging from relatively small adjustments in how they
24   run existing systems, to major capital improvements, to filtration or disinfection processes.
25
26   Systems should consider the impacts of any modifications they are considering, including
27   impacts related to the issues described in Sections 2.4 and 6.2. They should identify what
28   information they need to help them decide whether and how they can adjust their treatment to
29   comply. If they do not have that information, they should identify what monitoring is necessary
30   to obtain it. Subsection 6.3.1 provides resources system managers can use as guidance for
31   collecting data about their systems to help them make these decisions.
32
33   Subsection 6.3.2 describes available desktop studies that can be useful tools for decision-
34   making. Subsection 6.3.3 lists resources available about bench scale tests, including those
35   describing proper jar testing applications and procedures. These are all relatively inexpensive
36   ways for a system to determine whether it can comply by optimizing its existing treatment.
37
38   If a system opts to install new treatment, managers should proceed carefully and in an
39   informed way. They too should consider the issues described in Sections 2.4 and 6.2 and how
40   those issues affect what treatment should be installed.
41
42   Some water systems will have more resources available than others for evaluating the
43   potential impacts of a treatment change. The references provided in Section 6.3 give readers

1 perspective on how involved and expensive different evaluation tools can be. Water system
2 managers, particularly those with limited resources, are encouraged to take the time to make
3 informed decisions about what evaluations should be performed before a new treatment is
4 installed.
5
6
7   Finally, simultaneous compliance is a necessary consideration when deciding how to
8 proceed. System managers should use the information and references available throughout this
9 and other guidance manuals to make Stage 2 DBPR and LT2ESWTR compliance decisions with
10 confidence that all regulations will be met.
11
12
13 **6.2 Issues to Consider When Making a Compliance Decision**
14
15   As the previous chapters have indicated, numerous considerations must be taken into
16 account when deciding on the best strategy for complying with a new regulation. Factors must
17 be considered and balanced when coming to a conclusion that will satisfy all parties: system
18 owners; regulatory agencies; customers; and other stakeholders. The earlier sections of this
19 manual have laid out considerations for specific technologies. This section identifies issues to
20 consider whenever any change is made to a water system, including changes that may not be
21 discussed previously, such as novel technologies or seemingly minor operational changes.
22
23   Exhibit 6.1 summarizes the types of considerations that should be made before making
24 changes, along with some direction as to what kind of information would help decision-makers
25 during their review of those considerations.
26

1

Exhibit 6.1 Issues to Consider When Deciding How to Comply with Stage 2 DBPR and/or LT2ESWTR

Issue	Description of the Issue	Information to Help Systems Assess the Issue
Production Capability	• Quantity and quality of water may be an issue in arid or highly developed areas. • Systems operating at or near peak production capabilities are likely to be affected by decreases in production. • Some treatment technologies (e.g., enhanced filtration and anion exchange, membrane technologies) may lower production capacity. • Methods of lowering disinfection byproduct (DBP) production (e.g., changing storage tank fill/drain cycles, removing storage tanks) can affect the amount of storage available for droughts and fire fighting.	• Chapter 4, especially Sections 4.5 and 4.6, discuss issues with treatment technologies in more detail. • The amount of storage needed for uses such as droughts and fire fighting should be taken into account when making changes to distribution system storage. Hydraulic models as described in Section 6.3.2 can aid in making these determinations.
Compatibility with Existing Treatment Facilities	• A public water system (PWS) is a series of linked and inter-related processes that affect one another. Systems must consider the effects that changes or additions to any process in the system may have on other processes within the system. • Any modification that changes the chemical properties of the water such as pH, alkalinity, metals concentrations, or organic matter concentration will likely affect the coagulation and sedimentation process. • Adding new chemicals may cause corrosion of plant materials.	• Sections 3.3.4, 4.1.4, 4.3.4, and 5.5.6.1 provide examples of systems that faced issues as a result of changing processes. • Many known effects of technologies are discussed in the preceding chapters. Other effects may be specific to a particular water quality or other site-specific variables, or to a technology not discussed in this guidance manual. • Tools discussed in Section 6.3 (e.g., bench studies, pilot testing) are important for determining potential effects of system changes.

Issue	Description of the Issue	Information to Help Systems Assess the Issue
Production of Residuals and Disposal Issues	• Some process changes can affect the composition or cause the production of residuals or other wastes. Disposal of additional waste must be taken into account both when determining costs and in other considerations. • Systems should consider whether waste streams can be disposed of through sanitary sewer lines or if separate disposal means are required. Pretreatment requirements and requirements by the wastewater treatment plant should be investigated if sewer disposal is an option. • Process changes and changes in water quality (e.g., pH, alkalinity, metals concentrations, and organic matter) may affect the properties of residuals (e.g., the residual's density and its ability to be dewatered).	• Sections 3.6.2 and 3.7.2 provide more information on disposal of additional waste. • Combinations of jar tests and pilot tests can help determine changes that might occur and how best to deal with them, as described in sections 6.3.4 and 6.3.5, respectively.
Site Specific Issues	• System size and available resources vary widely and can impact compliance strategies. • Systems need to consider the number and skill of operators when making treatment decisions. • Systems need sufficient space for new technologies to be easily accessed for service and maintenance. • A system should consider how the addition of any new processes will affect the hydraulic gradient in the plant. • Location can be an important factor (e.g., price and availability of chemicals, delivery charges for equipment and chemicals, effect of the local climate on treatment processes).	• Sections 3.6.4 and 5.2.4 present examples of systems that faced challenges because of temperature differences. • System-specific studies must be carried out to determine how various issues will affect a system. Some issues can be sufficiently answered through literature reviews and discussions with manufacturer representatives. Others will need to be investigated more thoroughly using the techniques discussed in Section 6.3.

Issue	Description of the Issue	Information to Help Systems Assess the Issue
Compatibility with Distribution System Materials	• Changes to water quality, especially to pH, alkalinity, or redox potential, can affect corrosion both in the plant and in the distribution system. • Some types of distribution system surfaces (e.g., highly scaled iron pipes) lend themselves to easily releasing scale materials into the water if changes are made to water quality. • Any treatment change should be analyzed to determine if it will change the corrosion rate of system materials.	• Section 6.3 discusses desktop studies along with bench and pilot methods such as pipe loop studies, which can be used to determine changes in corrosion rates associated with a given change. • Section 6.3.1 discusses water quality monitoring, which can provide warning if corrosion rates do change unexpectedly after a treatment modification. • Section 5.1.4 shows how one system dealt with corrosion issues. • Appendix D also includes evaluation tools that can be used to determine changes in corrosion rates.
Compatibility with Distribution System Operations	• Treatment changes that change the chemical make-up of the water can affect the distribution system and may require changes in its operation. • Systems should consider corrosion issues and microbial stability of the system (some chemicals added to the water may promote microbial growth in the distribution system). Systems using chloramines may have an increased risk of nitrification problems. • Systems may need to make distribution system changes (e.g., more frequent flushing, reducing residence times) to counter increased microbial activity.	• Section 5.1.2 describes the nitrification problem with chloramines. • Section 6.3 describes models that can help to predict and circumvent problems such as nitrification.

Issue	Description of the Issue	Information to Help Systems Assess the Issue
Environmental Issues	• Changes to treatment or system operations may present environmental issues (e.g., change to flushing procedures to remove chloramines, which are toxic to fish, before water is discharged to natural waters). • Constituents added to drinking water may raise issues at the wastewater treatment plant (WWTP) (e.g., metals such as zinc, used in some corrosion inhibitors, may inhibit the denitrification process at the WWTP) because some treated water eventually ends up in the sewer system. WWTPs may also have discharge permit limits for water quality parameters like pH, metals, and phosphorus. • If a system needs to purchase new land for a treatment process or wants to change sources, environmental issues may arise such as the presence of wetlands or endangered species; discharges to a stream or surface water body (e.g. filter backwash water, well development water)	• Systems should review environmental regulations and WWTP requirements before making any major changes. Related environmental regulations may include SDWA Source Water Assessment Program and Wellhead Protection Program (State primacy agency); state regulations on wetland protection and river protection; and local zoning ordinances.
Consumer Driven Issues	• Changes may result in consumer complaints about tastes, odors, or colored water, which can arise from many different factors. Changes in water chemistry can cause corrosion, causing colored water at the tap. Tastes and odors can result from high disinfectant doses or from microbial activity encouraged by water chemistry changes. • Changes in water rates requires good communication • Good public education is important for public health protection and can head off consumer complaints.	• Section 6.3.4 and 6.3.5 describe bench-scale and pilot testing, which help predict if changes will cause undesired outcomes at the consumer's tap. • Section 6.3 describes ways to determine the sources of various taste and odor compounds. • Section 6.3.8 provides some resources for planning, such as public education efforts. • Section 5.1.2 discusses the importance of public education.

Issue	Description of the Issue	Information to Help Systems Assess the Issue
Preference of Operations Staff	• Operator preferences may be based on how chemicals are added, what forms of chemicals are used (e.g. hypochlorite vs. chlorine gas), the amount of automation, and positioning of equipment. • Positioning of equipment, safety, need for advanced training, and additional monitoring.	• Systems should solicit input from operations staff, since they are responsible for the day to day implementation of any changes, can raise valid concerns that others have not considered during the planning process, and understand the implications for training.
Consecutive System Requirements	• Systems selling some or all of their water to other systems will have to take into account the needs of the purchasing systems, which do not have treatment themselves. • Consecutive (purchasing) systems may have large distribution systems with long residence times. Water that is delivered may meet total trihalomethane (TTHM) maximum contaminant levels (MCLs) at delivery but may exceed them nearer the end of the distribution system. • Mixing different types of disinfectant residuals can cause problems if not done very carefully.	• EPA's *Draft Consecutive Systems Guidance Manual* (USEPA 2005a) provides helpful information that guides decision-making for consecutive systems.
Cost	• Cost has an impact on decisions about compliance strategies, but must include all of the previous considerations.	• Section 6.3.7 describes several computer models that can help with costing various technologies.

1

6.3 Tools for Gathering Information

The objective of this section is to provide examples of tools that can assist utilities to evaluate and improve their current water system in relation to the compliance of Total Coliform Rule (TCR), Lead and Copper Rule (LCR), LT2ESWTR, and Stage 2 DBPR. These tools include computer software, models, technical publications, and research reports that can be acquired through public domains, non-profit organizations, or private companies. While some of the tools can be obtained freely from government agencies or internet (such as reports and guidance manuals from EPA), the acquisition of some tools may either require member subscription (such as reports from AwwaRF) and/or fees (such as AWWA publications and proprietary software).

These tools are organized into the following eight categories:

- ✓ Water quality monitoring
- ✓ Hydraulic and water quality modeling for distribution systems
- ✓ Desktop evaluations
- ✓ Bench-scale testing
- ✓ Pilot testing
- ✓ Full-scale applications
- ✓ Cost estimation
- ✓ Community preferences

A subsection is dedicated to each of these categories and a brief introduction is included to describe the purpose of tools in that category and the relations to other subsections. The application of these tools at various project implementation stages is summarized in Exhibit 6.2.

This document does not intend to provide a comprehensive list of tools that may be used to assist in simultaneous regulatory compliance, but rather to provide examples of available tools. Readers of this document should consult with regulatory agencies and professional organizations for other similar tools and updated information.

1   **Exhibit 6.2 Application of Information Gathering Tools at Various Project**
2   **Implementation Stages**

Tool Type	Planning	Evaluating Compliance Options	Design	Operation /Monitoring
Water quality monitoring	X	X		X
Hydraulic and water quality modeling for distribution systems	X	X		X
Desktop evaluations	X	X		
Bench-scale testing		X	X	X
Pilot testing		X	X	
Full-scale applications	X	X	X	
Cost estimation	X	X		
Community preferences	X	X		X

3
4
5   This document does not intend to provide a comprehensive list of tools that may be used to assist
6   in simultaneous regulatory compliance, but rather to provide examples of available tools.
7   Readers of this document should consult with regulatory agencies and professional organizations
8   for other similar tools and updated information.
9
10   **6.3.1   Water Quality Monitoring**
11
12   Tools included in this section provide guidance and methodologies for monitoring water
13   quality in water supplies, water treatment facilities, and transmission and distribution systems.
14   The first five tools are EPA documents that describe water quality sampling requirements for
15   various regulations. Utilities should consult with these documents to meet the minimum
16   monitoring requirements for the compliance of each regulation.
17
18   •   **Total Coliform Rule: A Quick Reference Guide (USEPA 2001f).** This EPA
19   document provides updated information on water quality monitoring requirements for
20   the TCR. This document can be obtained from the following EPA Web site:
21   *http://www.epa.gov/safewater/tcr/pdf/qrg_tcr_v10.pdf*.
22
23   •   **A Small System Guide to the Total Coliform Rule (USEPA 2001g).** This EPA
24   document provides guidance on monitoring requirements for small systems that serve
25   3,300 or fewer people. This document can be obtained from the following EPA Web
26   site: *http://www.epa.gov/safewater/smallsys/small-tcr.pdf*.
27

- **Drinking Water Regulations; National Primary Drinking Water Regulations for Lead and Copper Rule (USEPA 2000b) & Lead and Copper Rule Minor Revision Fact Sheet (USEPA 1999i).** These two documents summarize the monitoring requirement of the LCR. The quick reference guide of LCR can be found at the following EPA Web site: *http://www.epa.gov/safewater/lcrmr/pdfs/qrg_lcmr_2004.pdf*

- **Source Water Monitoring Guidance For the Long Term 2 Enhanced Surface Water Treatment Rule (USEPA 2006d).** This EPA guidance manual provides detailed water quality sampling procedures and requirements for the LT2ESWTR. The primary monitoring target of this rule is a chlorine-resistant parasite: *Cryptosporidium parvum* oocyst, a protozoan oocyst.

- **The Stage 2 DBPR Initial Distribution System Evaluation Guidance Manual (USEPA 2006a).** This EPA document provides distribution system water quality monitoring requirements for the Stage 2 DBPR. This guidance manual describes the monitoring frequency, number of sampling locations, and the methodologies for selecting appropriate sampling locations for TTHM and HAA5.

- **Design of Early Warning and Predictive Source-Water Monitoring Systems (AwwaRF Report 90878, Grayman et al. 2001).** This research report provides guidance on the development of early warning systems for real-time source water contaminant monitoring. These systems will allow utilities to predict water quality events in the source water that may require subsequent treatment adjustment in the water treatment facilities.

- **Guidance Manual for Monitoring Distribution System Water Quality (AwwaRF Report 90882, Kirmeyer 2002).** This document provides water utilities with guidance on how to design and implement a distribution system water quality data collection and analysis program. This document features a comprehensive approach for collecting and analyzing water quality information, providing important input to costly infrastructure improvements, documenting benefits of operational procedures, and addressing consumer complaints.

- **Methods for Real-Time Measurement of THMs and HAAs in Distribution Systems (AwwaRF Report 91003F, Emmert 2004).** This document summarizes existing technologies and methods that can be used to quantify concentrations of total THMs and the sum of the five regulated HAA5 in near-real time. Some of the methods are also capable of quantifying individual THM and HAA species.

- **Optimizing Corrosion Control in Water Distribution Systems (AwwaRF Report 90983, Duranceau et al. 2004).** This report demonstrates the use of a multi-element

1   sensor electrochemical technique for instantaneously monitoring corrosion and
2   optimizing corrosion control in water distribution systems. This document also
3   describes the uses of real-time corrosion sensors to screen various corrosion
4   inhibitors.
5
6 • You may go to the following documents for national occurrence information to
7   determine how your source water compares with source waters of other systems, and
8   to get a sense of the technologies being commonly used by water systems with source
9   water quality similar to yours.
10
11
12   o USEPA. 2005c. *Stage 2 Occurrence Assessment for Disinfectants and*
13   *Disinfection Byproducts*. EPA 815-R-05-011
14
15
19   o USEPA. 2003k. *Occurrence and Exposure Assessment for the Long Term 2*
20   *Enhanced Surface Water Treatment Rule*. EPA 815-R-06-002
21
22   o McGuire, M.J., J.L. McLain, and A. Obolensky. 2002. Information Collection
23   Rule Data Analysis. Awwa Research Foundation and AWWA, Denver.
24
25 **6.3.2   Hydraulic and Water Quality Modeling for Distribution System**
26
27   While documents listed in the previous section provide guidance on monitoring actual
28 water quality, tools described in this section provide means to predict and model water quality
29 changes in the distribution system based on the calculation of hydraulic retention time (water
30 age), kinetics of water chemistry, and parameters that could affect water chemistry (e.g.,
31 temperature, pipe material, etc.). In addition to water quality modeling, most of these tools are
32 also capable of hydraulic modeling. Results from these modeling exercises can assist utilities in
33 projecting distribution system water quality and planning for simultaneous compliance.
34
35 • **EPANET (USEPA 2002b). Developed by EPA, EPANET 2.0** is a Windows based
36   computer program that performs extended period simulation of hydraulic and water
37   quality behavior within pressurized pipe networks. It is available at the following
38   EPA Web site: *http://www.epa.gov/ORD/NRMRL/wswrd/epanet.html*. Several
39   software companies (including DHI, MWH Soft, Haestad Methods, and Wallingford
40   Software) use EPANET as the foundation to develop their proprietary versions of
41   hydraulic and water quality modeling tools. These commercial programs provide
42   similar functions to that by EPANET, but may be more flexible, and user-friendly.
43
44 • **SynerGEE® Water. Developed by Advantica, SynerGEE** Water is a simulation
45   software package for modeling and analyzing water distribution systems. It is
46   capable of conducting steady state analysis, dynamic analysis, and the analyses of
47   water age, source contribution, water quality, fireflow, and pump operating costs.

1
2   • **Water Quality Modeling of Distribution System Storage Facilities (AwwaRF**
3   **Report 90774, Grayman 2000).** This document describes procedures that can be
4   used to characterize water quality conditions and changes in water storage reservoirs.
5   This report also provides a hydraulic model with a water quality model that can be
6   used to determine the effects of daily fill and draw cycles. Optimum design and
7   operation of distribution system tanks and reservoirs is also addressed.
8
9   • **Predictive Models for Water Quality in Distribution Systems (AwwaRF Report**
10   **91023F, Powell 2004).** This research report provides a comprehensive review of the
11   current state of predictive water quality modeling covering water quality processes
12   models for corrosion and metal release, discoloration, disinfectant decay, DBPs, and
13   microbial water quality. This review also describes how these models can be applied
14   to distribution networks, including water quality network models, storage tank
15   models, and zone level models.
16
17   • **Computer Modeling of Water Distribution Systems (AWWA 2004a).** This
18   manual provides step-by-step instructions for the design and use of computer
19   modeling for water distribution systems. Distribution system operators can build an
20   accurate and detailed "virtual" model of the system using computer software.
21   Computer models can help the operators to uncover problems and explore different
22   scenarios to solve the problems without actually entering or changing the physical
23   distribution system. This manual also includes results from a survey of U.S. and
24   Canadian water utilities on future trends of water distribution and water quality
25   modeling.
26
27   **6.3.3   Desktop Evaluations**
28
29   Desktop evaluation tools included in this section can be used to assist utilities in
30   evaluating and optimizing treatment strategies to comply with LT2ESWTR and Stage 2 DBPR.
31   These tools are particularly helpful in identifying the best combination of treatment components
32   for simultaneous regulatory compliance.
33
34   • **Water Treatment Plant Model (Version 2.0) (USEPA 2001h).** Originally
35   developed by EPA in 1992 to support Stage 1 Disinfectants/Disinfection Byproducts
36   Rule (D/DBPR), the Water Treatment Plant Model was updated in 2001 to include
37   more data and alternative treatment processes to assist utilities in achieving total
38   system optimization (TSO), i.e., a method by which treatment processes can be
39   implemented such that a utility meets the required levels of disinfection while
40   maintaining compliance with requirements of Stage 1 and, potentially, Stage 2 DBPR.

- **The Surface Water Analytical Tool (Version 1.1) (USEPA 2001i).** Developed by EPA, Malcolm Pirnie, and TPMC, the Surface Water Analytical Tool (SWAT) can be used to select treatment processes to meet the Stage 2 DBPR and desirable disinfection level.

- **Draft Significant Excursion Guidance Manual (USEPA 2003c).** The purpose of this guidance manual is to provide technical information and guidance for water systems and States to use for identifying and reducing significant excursions of DBP levels.

- **Self-Assessment Guide for Surface Water Treatment Plant Optimization (AwwaRF Report 90736, Renner and Hegg 1997).** This self-assessment guide was developed to assist water utilities in evaluating their ability to produce reliable and consistent supplies of high quality treated drinking water with maximum removal of microbial contaminants. With the completion of the self-assessment, a water utility can evaluate its current level of plant performance with respect to turbidity goals and determine if performance improvements are needed. This self-assessment helps the utility to identify the reasons for less-than-optimum performance and implement appropriate improvements.

- **The Rothberg, Tamburini & Winsor Blending Application Package 4.0 (AWWA 2001a).** This new RTW program is the successor of *Model for Water Process and Corrosion Chemistry 4.0*. This computer program is developed to simplify the task of evaluating water chemistry associated with precipitation/coagulation and corrosion potential of water. The model provides prediction on the change of water quality (such as pH, hardness, alkalinity, and Langelier Saturation Index) in response to the changes in operating conditions. The new version can handle more than one water source under multiple blending scenarios. Although the RTW model adequately predicts the changes in water quality, any intent of correlating these information to actual corrosion potential should also include more detail and direct corrosion assessment as described in other sections of this document.

- **Metals Solubility Prediction Tools.** Additional models have been developed to evaluate the solubility of metals in the distribution system. The AWWARF report, *A General Framework for Corrosion Control Based on Utility Experience and Control of Pb and Cu Corrosion By-Products Using CORRODE Software.* (Edwards and Reiber 1997) includes chemical equilibrium software that can be used to identify causes of corrosion problems and test the validity of different corrosion control strategies. The USGS PHREEQC is a computer program designed to perform a wide variety of low-temperature aqueous geochemical calculations. Information on PHREEQC is available on the USGS website at *http://wwwbrr.cr.usgs.gov/projects/GWC_coupled/phreeqc/*

1
2   **6.3.4   Bench-Scale Testing**
3
4   This section includes bench-scale testing procedures and methods for acquiring technical
5   information on water quality, treatment efficacy, and internal corrosion potential. This
6   information is critical to water quality modeling and system evaluation and optimization. Five
7   categories of bench-scale testing methods are presented in this section, including:
8
9   ◆ Disinfectant Demand and Decay
10   ◆ DBP Growth and Decay
11   ◆ Taste and Odor Profiles
12   ◆ Jar/Column Testing Procedures
13   ◆ Internal Corrosion Assessment
14
15   Each of these bench-scale testing tools is described follow.
16
17   • **Disinfectant Demand and Decay**
18
19   o **Standard Method 2350, Oxidant Demand/Requirement (APHA et al. 1998).**
20   Information on chlorine demand in the transmission and distribution system is critical to
21   the assurance of public health as well as an effective internal control practice. Increasing
22   chlorine dosage to compensate excessive chlorine demand may also result in high DBP
23   formation. This standard method provides step-by-step instruction on four methods for
24   the determination of oxidant demands: one method each for chlorine and chlorine dioxide
25   and two methods for ozone (batch and semi-batch methods).
26
27   • **DBP Formation and Decay**
28
29   o **Field and material-specific simulated distribution system testing as aids to**
30   **understanding trihalomethane formation in distribution systems (Brereton and**
31   **Mavinic 2002).** This paper presents results from a comprehensive study using an
32   extensive field monitoring program and an improved simulated distribution system (SDS)
33   bench-scale test. The SDS bench test includes the potential increased chlorine demand
34   caused by internal pipe walls in the evaluation of DBP formation. During field testing,
35   this study compared both pre-formed THM and THM formation potential among several
36   distribution system locations to eliminate inherent uncertainties associated with the
37   complexities of network hydraulics, leaving exposure to the internal pipe environment as
38   the primary factor of interest. Findings in this paper suggest the reliability of using the
39   material-specific SDS (MS-SDS) test is a better representation of DBP evolution in a real
40   distribution system. The MS-SDS test is readily adaptable for pilot-plant studies where
41   real distribution system conditions are inaccessible. This article can be acquired from the

following internet Web site: *http://pubs.nrc-cnrc.gc.ca/cgi-bin/rp/rp2_abst_e?cjce_l01-074_29_ns_nf_cjce*.

o **Simulated Distribution System DBP development procedure**

- *Predicting the formation of DBPs by the simulated distribution system* (Koch et al. 1991). This study developed a simulated distribution system (SDS) method that can be used to predict the amounts of DBPs that would form in a distribution system. Key parameters (including chlorine dosage, incubation temperature, and incubation holding time) are chosen to simulate the conditions of the treatment plant and the distribution. Results from this study show good correlation between the SDS samples and the samples collected from the distribution systems.

- *Assessing DBP yield: uniform formation conditions* (Summers et al. 1996). This paper presents a new chlorination approach, the uniform formation conditions (UFC) test. The UFC test can be used to assess disinfection DBP formation under constant, yet representative conditions. Results from this study suggest that UFC test can be used for a direct comparison of DBP formation among different waters and allows the evaluation of how treatment changes affect DBP formation in a specific water.

- **Taste and Odor Profiles**

o **Practical Taste-and-Odor Methods for Routine Operations: Decision Tree (AwwaRF Report 91019, Dietrich 2004)**. This report describes the existing and newly developed sensory methods for monitoring the taste-and-odor quality of drinking water, as well as the odor quality of source or partially treated water, in order to understand the reasons for customers' attitudes and complaints, to make decisions for treatment, to track problems to their sources, and to provide early warning of problems that are expected to recur. The new methods are described in detail in this report while existing methods are already described in Standard Methods for the Examination of Water and Wastewater (APHA 1998). The new methods provide early warning to geosmin and 2-MIB, information about treatment, information for the approval of new installations in distribution, and the confirmation of customer complaints.

o **Water Utility Self-Assessment for the Management of Aesthetic Issues (AwwaRF Report 90978F, McGuire et al. 2004).** This report provides guidance for utility to conduct self-assessment on its T&O control strategies. This self-assessment tool improves a utility's ability to quickly identify the source of problems, implement control strategies, and communicate with its stakeholders.

- **Jar/Column Testing Procedures**

    o **Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual, Section 3: The Step 2 Procedure and Jar Testing (USEPA 1999h).** This document provides procedures for conducting jar testing to determine the optimum coagulation conditions for achieving desirable total organic carbon (TOC) removal and coagulated/settled water turbidity. This document can be found at the following EPA Web site: *http://www.epa.gov/safewater/mdbp/coaguide.pdf*.

    o **Procedures Manual for Polymer Selection in Water Treatment Plants (AwwaRF Report 90553, Dentel et al. 1989).** This manual describes the bench-scale testing protocols for the selection of coagulants as well as the appropriate types of polymer for coagulant aids, filter aids, and sludge dewatering aids.

    o **Operational Control of Coagulation and Filtration Processes (AWWA Manual M37, AWWA 2000).** This manual provides information on standard jar testing procedure for bench-scale coagulation testing.

    o **Enhanced and Optimized Coagulation for Particulate and Microbial Removal (AwwaRF Project #155, Bell et al. 2001).** This research project evaluated the effect of enhanced and optimized coagulation on particulate and microbial removal. This study demonstrates the use of bench-scale studies on 18 waters corresponding to the EPA TOC – alkalinity matrix and removal of protozoan cysts and oocysts, viruses, enteric bacteria, spores, and bacteriophage. The bench-scale jar testing protocol described in this report can be used to determine the optimum coagulant type, coagulant dose, and coagulation pH for the compliance of Stage 2 DBPR as well as LT2ESWTR and TCR.

    o **Design of Rapid Small-Scale Adsorption Test for a Constant Diffusivity (Crittenden et al. 1986)** This paper describes the fundamental theory and bench scale testing procedure for using a small adsorptive media column to quickly predict effective GAC adsorption capacity for specific organic compounds in full-scale operation. This technique, know as RSSCT, has been widely accepted by chemical engineering industry and has also been used to estimate useful GAC life time when used for the removal of aquatic organic contaminants.

    o **Prediction of GAC Performance Using Rapid-Small Scale Column Tests (AwwaRF Project #230, Crittenden 1989)** This document describes the use of RSSCT techniques to predict full-scale GAC useful life time when it is used to remove dissolved organic matter in drinking water source. This report also demonstrates how to use pilot-scale testing data to further refine the RSSCT prediction.

- **Internal Corrosion Assessment**

  o **Internal Corrosion of Water Distribution Systems (AwwaRF Report 90508, AWWARF and DVGW-Technologiezentrum Wasser 1996).** This report covers a wide range of topics related to internal corrosion, such as corrosion principles, corrosion of various materials including copper alloys and solder, mitigation of corrosion impacts, assessment technologies, and approaches to corrosion control studies. This document also describes a bench-scale testing protocol of using various techniques (such as electrochemical techniques and coupon techniques) to evaluate corrosion potential. Other useful topics covered by this report include types of chemicals used for corrosion control, corrosion assessment options for metal plumbing materials, water quality conditions that affect corrosion of various types of materials, and benefits and drawbacks of bench testing versus flow-through pipe loops.

6.3.5 Pilot Testing

After performing water quality monitoring, modeling, and desktop analyses, a utility may decide to implement specific technologies to comply with certain regulations. In some cases pilot testing is desired prior to the implementation of the selected technologies. Tools described in this section provide guidelines on how to conduct pilot testing in order to obtain information on performance, design, operation and maintenance issues, and cost estimation. Since technology development proceeds at a very fast pace in the water industry, to ensure a successful project, utilities are strongly encouraged to consult with experienced engineers, reputable equipment providers, and regulatory agencies when planning a pilot testing program.

- **Membrane Filtration Guidance Manual (USEPA 2005b).** The purpose of this guidance manual is to provide technical information on the use of membrane filtration and application of the technology for compliance with the LT2ESWTR, which would require certain systems to provide additional treatment for Cryptosporidium. Section 6 of this guidance manual provides general guidelines for membrane pilot testing. Utilities who are considering using membrane technology to comply with LT2ESWTR should consult with this document before conducting on-site pilot testing and membrane selection. This document can be found at the following EPA Web site: *http://www.epa.gov/safewater/disinfection/lt2/compliance.html*

- **Ultraviolet Disinfection Guidance Manual (USEPA 2003b).** Similar to the Membrane filtration Guidance Manual, this manual provides guidance on the validation, selection, design, and operation of ultraviolet (UV) disinfection to comply with treatment requirements under the LT2ESWTR. Appendix J of this guidance manual provides general guidelines for UV disinfection pilot testing. Utilities who are considering using UV technology to comply with LT2ESWTR should consult

1   with this document before conducting on-site pilot testing and equipment selection.
2   The final version of the document will be posted on EPA's web site:
3   *http://www.epa.gov/safewater/disinfection/lt2/compliance.html*
4

5   • **Long Term 2 Enhanced Surface Water Treatment Rule: Toolbox Guidance**
6   **Manual (USEPA 2003a).** While there is no specific standardized pilot testing
7   protocol developed for each of the treatment processes identified in the LT2ESWTR
8   Toolbox, with the exception of UV and membranes, this Toolbox Guidance Manual
9   provides a general guidance on the Demonstration of Performance (DOP) protocol
10   that can be used as the guideline to develop a specific pilot testing protocol for each
11   treatment technology of interest. The final version of the document will be posted on
12   EPA's Web site: *http://www.epa.gov/safewater/disinfection/lt2/compliance.html*
13

14   • **Internal Corrosion of Water Distribution Systems (AwwaRF Report 90508,**
15   **AWWARF and DVGW-Technologiezentrum Wasser 1996).** As described in the
16   Bench-Scale Testing section, this report provides a wide range of useful information
17   on internal corrosion, including the description of an on-site pilot testing protocol for
18   using a single-pass pipe loop tester to evaluate corrosion potential.
19

20 **6.3.6   Full-Scale Applications**
21

22   This section provides useful guidelines and tools for utilities to conduct treatment plant
23 assessment and optimization. The goals for these exercises are to improve treatment
24 performance and to comply with multiple regulations without major capital expenditure.
25 Treatment enhancement through these practices is usually achieved by optimizing operating
26 conditions and minor equipment updates or additions. Major capital improvement, such as the
27 construction of a new membrane facility, is not within the scope of these plant optimization
28 protocols, but may be needed after other options are exhausted.
29

30   • **Comprehensive Performance Evaluations (CPE***). Optimizing Water Treatment*
31   *Plant Performance Using the Composite Correction Program* **(USEPA 1998a).**
32   This handbook consists of two components: the Comprehensive Performance
33   Evaluations (CPE) and Comprehensive Technical Assistance (CTA). The CPE
34   provides a set of tools that assist a utility to review and analyze its performance-based
35   capabilities and associated administrative, operations, and maintenance practices.
36   The goal of CPE is to help a utility to identify factors that might adversely impact a
37   plant's ability to achieve permit compliance without major capital improvements.
38   The CTA provides guidance for the performance improvement phase once the CPE
39   identifies performance improvement potential. Information on this EPA manual can
40   be found at the following EPA Web site:
41   *http://www.epa.gov/ORD/NRMRL/pubs/625691027/625691027.htm*.
42

- **Texas Optimization Program (TNRCC 2005).** The Texas Optimization Program (TOP) is a voluntary, non-regulatory program designed to improve the performance of existing surface water treatment plants without major capital improvements. Information on TOP can be found at the following Web site: *http://www.tnrcc.state.tx.us/permitting/waterperm/pdw/top.html*.

- **Self-Assessment for Treatment Plant Optimization (Lauer 2001).** This guidebook presents protocols on how to optimize conventional treatment plants without investing in major capital improvements. This document provides procedures for optimizing particulate removal and disinfection through improvements in administration, maintenance, design, and operations.

- **Full Scale Implementation of UV in Groundwater Disinfection Systems (AwwaRF Report 91024, Malley 2001).** This document identifies key issues related to full-scale UV implementation, including the importance of UV reactor hydraulic design, water quality evaluation, sensor calibration, and proper cleaning techniques to insure optimal UV performance. The report provides specific guidance for the selection, design, and operation of UV systems.

- **Integrating UV Disinfection Into Existing Water Treatment Plants (AWWARF Report 91086. Cotton et al. 2006.).** This document provides user-friendly web tools that will assist utilities in assessing important disinfection decisions and UV implementation issues. This report also finds that power quality will most likely not cause a water utility to exceed the proposed regulatory requirements on UV application; however, power quality problems may reduce operational flexibility as well as UV lamp operations. The analysis protocol for the *Cryptosporidium* downtime and off-specification risk assessment could be used to assist regulators in developing criteria based on *Cryptosporidium* occurrence and risk.

- **Handbook of Public Water Systems, Second Edition (HDR, 2001)** This handbook provides detailed engineering design information for various drinking water treatment processes, including granular activated carbon.

- **Integrated Membrane Systems (AwwaRF Report 90899, Schippers et al. 2004)** This document provides guidance on the selection, design, and operation of an integrated membrane system that can function as a synergistic system for removing microbiological contaminants and DBP precursors. The integrated system may include membranes (including RO, NF, UF, and MF) and any pre- or post-treatment. This document also provides procedures for bench and pilot testing for membrane elements.

- **Integrating Membrane Treatment in Large Water Utilities (AwwaRF Report 91045F, Brown and Hugaboom 2004)** This study addresses issues related to the integration of low pressure membranes into existing or planned water treatment facilities. Results from this study can be used as guidance for membrane layout, piping, cost comparison, and operations and maintenance.

- **NOM Rejection by, and Fouling of, NF and UF Membranes (AwwaRF Report 90837, Amy et al. 2001)** Nanofiltration (NF) membranes can effectively remove natural organic matter (NOM) from a water supply, while ultrafiltration provides very limited NOM removal capability. This report provides information on the selection of appropriate membranes to achieve high NOM rejection, and also presents information on how water quality (such as the presence of calcium and pH) and operational conditions might affect NOM rejection by NF membranes.

- **Evaluation of Riverbank Filtration as a Drinking Water Treatment Process (AwwaRF Report 90922, Wang et al. 2002)** This reports describes the effectiveness of using river bank filtration for the removal of DBP precursors and microbial contaminants as a function of design and operation variables. This document also provides a general guideline for riverbank system design and operation.

6.3.7   Cost Estimation

Accurate cost estimation for facility upgrades requires a comprehensive database that consists of updated equipment and construction cost information. While engineering consultants and construction companies usually keep their proprietary cost estimation tools refined and updated with major cost indices, very few cost estimation tools for drinking water industry are available to the general public. The cost estimation tools listed in this section represent the starting points for budgetary planning. It is recommended that utility budgetary planning personnel should consult with the authors of these tools and the additional information sources listed at the end of this section for a more accurate and updated cost estimation.

- **1999 Drinking Water Infrastructure Needs Survey: Modeling the Cost of Infrastructure (USEPA 2001j).** This document provides cost models for water sources (such as surface water intake, well development, and aquifer storage & recovery wells), various treatment processes, storage, transmission/distribution systems, pumping, and other (i.e., SCADA). The cost of rehabilitation is also provided along with new installation in some cases.

- **W/W Costs, Windows Version 3.0, *Copyright 1994-2000, George Mack Wesner, PhD, PE.*** This computer software provides detailed capital and O&M costs of any combination of treatment processes based on the treatment processes and design

1   criteria selected by the users. It should be noted that not all of the cost information of
2   every treatment component were updated during the 2000 revision.
3

4   • **WTCost©, 2003.** This computer program is developed by the U.S. Bureau of
5   Reclamation and I. Moch & Associates (sponsored by the American Membrane
6   Technology Association, AMTA) for estimating membrane treatment plant costs. It
7   allows the evaluation and comparison of water treatment processes that employ
8   reverse osmosis/nanofiltration, electrodialysis, microfiltration/ultrafiltration, and ion
9   exchange. Using flexible cost indices and adjustable inputs, WTCost includes costs
10   equations for estimating different pre and post treatment unit operations such as
11   gravity media filtration; coagulation and flocculation with powered activated carbon
12   (PAC), granulated activated carbon (GAC), alum, ferric chloride ferrous sulfate or
13   polyelectrolyte; disinfection by chlorine, monocloramine, ozone and UV; lime/soda
14   softening; electrical, including energy recovery, and chemical consumption and
15   various intake and outfall infrastructures. Labor and supervision, membrane
16   replacements, amortization rates and tanks, piping and instrumentation are also
17   included in the cost model, permitting calculation of plant capital requirements and
18   operating and maintenance costs.
19

20   • **WaterCAD (Haestad Methods).** This commercial software can be used to design
21   and analyze distribution systems, including pipelines and pump stations. With the
22   Cost Manager component, this program is capable of assessing the capital costs
23   associated with the water distribution network including pumps, valves, and storage
24   facilities and recommend future improvements based on both hydraulic and financial
25   impacts. Another cost function provided by this program is to estimate energy costs
26   for constant speed and variable-speed pumps. This program can further examine the
27   tradeoffs between energy costs and the capital costs required to improve pump
28   efficiency.
29

30   • **USEPA 2005d.** *Technologies and Costs for Control of Microbial Contaminants*
31   *and Disinfection Byproducts.* Office of Ground Water and Drinking Water.
32   Standards and Risk Reduction Branch. Standards and Risk Management Division.
33   U.S. EPA Contract 68-C-02-026. May 2003. While this publication does not provide
34   system-specific cost information, systems may use it to determine approximate and
35   relative costs.
36

37   • **Additional Resources for Cost Information**
38

39   o Most recent cost information or cost curves of a specific technology are published
40   in professional journals or conferences
41

1   o   Utilities from the same region that have conducted similar projects at similar scale
2   in recent years
3
4   o   Reputable equipment suppliers
5
6   o   Reputable engineering consultants
7

6.3.8   Community Preferences

9
10   This section includes six AwwaRF research reports that provide utility survey data and
11   practical guidance to assist water utilities in improving their customer communications, public
12   perception, and public involvement of the water quality issues, regulatory compliance issues, and
13   potential capital improvement projects.
14

15   •   **Consumer Attitude Survey Update (AwwaRF Report 394, AwwaRF 2000).** This
16   report discusses trends in public confidence and expectations, perceptions, and
17   satisfaction. Also identified in this report are the driving factors behind these
18   attitudes and trends and the impact of media on public confidence and customer
19   satisfaction. The implications of these findings for measuring customer attitudes at
20   the local utility level are also discussed.
21

22   •   **Tools and Methods to Effectively Measure Customer Perceptions (AwwaRF**
23   **Report 90856, Colbourne 2001).**   This report evaluates available assessment tools
24   and methods that measure customer perceptions and changes in their opinions toward
25   drinking water utilities and utility services.
26

27   •   **Best Practices for a Continually Improving Customer Responsive Organization**
28   **(AwwaRF Report 90868, Olstein 2001).** This report provides case studies of five
29   successful customer-driven water utilities that have used different approaches to
30   achieving a continually improving customer responsive organization. This document
31   presents public input to the best practices, and a toolkit for utilities that includes a
32   self-assessment questionnaire, a technology identification matrix, and benchmarking
33   data.
34

35   •   **Public Involvement . . . Making It Work (AwwaRF Report 90865, Nero et al.**
36   **2001).** In 1995, AwwaRF published the *Public Involvement Strategies: A Manager's*
37   *Handbook* (AwwaRF 1995) to provide a framework for building consensus on
38   difficult decisions. It presents a ten-step process to help water utility managers
39   identify, understand, and plan public involvement and project implementation. This
40   new report reduces the ten-step public involvement process to three essential steps,
41   and provides a new handbook to guide utility managers through the public
42   involvement process.
43

- **Public Involvement Strategies on the Web (AwwaRF Report 90865, AwwaRF 2003).** This web-based interactive tool was provided by AwwaRF in 2003 to expand the **AwwaRF Report 90865** (Nero et al. 2001) by offering public involvement case studies and interactive features on the internet. This interactive tool can be found at the following AwwaRF Web site: *http://www.awwarf.org/research/TopicsAndProjects/Resources/webTools/ch2m/default.html*.

- **Customer Attitudes, Behavior and the Impact of Communications Efforts (AwwaRF Report 90975, Tatham et al. 2004).** This report provides guidelines on the following three areas that are critical to communication with customers: (1) determine whether or not communication can be used as a tool by water utilities to positively affect the attitudes and behaviors of residential water utility customers, (2) identify the types of information that should be communicated by water utilities to enhance customer satisfaction and the methods for communicating this information to customers, and (3) reports on ways to inform customers about water quality issues, and provides guidance on communication strategies. This report includes a CD-ROM that contains 18 Microsoft Word documents that illustrate the survey data for various demographic groups.

- **Effective Practices to Select, Acquire, and Implement a Utility CIS (AwwaRF Report 91071, Rettie et al. 2005).** This report provides guidance to utilities as they select, acquire, and implement a customer information system (CIS). Guidelines provided in this document focus on four areas: (1) characterizing the current status of water utilities regarding CIS solutions, (2) identifying and documenting critical success factors (and barriers to success) related to CIS implementations, (3) documenting successful CIS implementations and associated practices, and (4) providing a CIS projects roadmap for utilities.

1   This page intentionally left blank.

.

1
2
3
4   **7 References**
5
6
7
8   The references in this chapter have been organized as follows under the following headings in
9   Section 7.1, with a complete alphabetical list in Section 7.2:
10

29
30
31   **7.1   References Organized by Topic**
32
33   **7.1.1   General**
34
35   Angers, J. 2001. Question of the Month: Which Disinfectant Will Work Best for Us?
36   Opflow. 27(5): 6-7, 22.

37   AWWA. 1990. Water Quality and Treatment. F.W. Pontius (editor). McGraw-Hill, New
38   York, NY.

39   AWWA. 1999c. Water Quality and Treatment: A Handbook of Community Water
40   Supplies. Fifth Edition. Letterman, R.D. (editor). McGraw-Hill

1   AWWA. 1999d. Design and Construction of Small Water Systems, Second Edition. 228
2   pp.

3   AWWA. 1999e. Hydraulic Design Handbook. Mays, L.W.(editor). McGraw-Hill.

4   AWWA. 2000. Operational Control of Coagulation and Filtration Processes. 2nd Edition.
5   AWWA Manual M37. pp. 1-34.

6   AWWA. 2005. Biodegradable Organic Matter in Drinking Water Treatment and
7   Distribution. M. Prevost et al. (editor).

8   AWWARF and Lyonnaise des Eaux. 1995. Advances in Taste and Odor Treatment and
9   Control. AWWARF Report 90610. Project #629.

10   Becker, W.C., K. Au, C.R. O'Melia, and J.S. Young, Jr. 2004. Using Oxidants to
11   Enhance Filter Performance. AWWARF Report 90998. Project #2725.

12   Connell, G. 1996. The Chlorination/Chloramination Handbook. AWWA. Denver, CO.
13   174 pp.

14   Culp, G.L. and R.L. Culp. 1974. New Concepts in Water Purification. Van Norstrand
15   Reinhold Co., New York.

16   DeMers, L.D. and R.C. Renner. 1993. Alternative Disinfection Technologies for Small
17   Drinking Water Systems. AWWARF Report 90619. Project #621.

18   Dewettinck T., E. Van Houtte, D. Geenens, K. Van Hege, and W. Verstraete. 2001.
19   HACCP (Hazard Analysis and Critical Control Points) to Guarantee Safe Water Reuse
20   and Drinking Water Production--a Case Study. Water Science and Technology. 43(12):
21   31-8.

22   DeWolfe, J. et al. Guidance Manual for Coagulant Changeover. AWWARF Report
23   90958. Project #2512.

24   Faust, S. and O. Aly. 1998. Chemistry of Water Treatment. Second Edition. Lewis
25   Publishers. New York.

26   Finch, G.R., D.W. Smith, and M. Belosevic. 2001. Sequential Disinfection Design
27   Criteria for Inactivation of Cryptosporidium Oocysts in Drinking Water. AWWARF
28   Report 90831. Project #348.

29   Friedman, M. and G. Hamilton. 1997. Enhancing CTs, Coagulation, and Corrosion
30   Control through Carbon Dioxide Injection. Proceedings 1996 Water Quality Technology
31   Conference, Part II. American Water Works Association.

1   Global Environment & Technology Foundation. 2000. Final Report: The US EPA
2   Environmental Management System Pilot Program for Local Government.

3   Global Environment & Technology Foundation. 2002. Final Report: Second EMS
4   Initiative for Government Entities (2000-2002).

5   Grant, G.B. Sc., CEA, EMS(LA), CEAS. 2004. ISO 14001 and Drinking Water Quality.
6   Environmental Science and Engineering. January, 2004.

7   HDR Engineering, Inc. 2001. Handbook of Public Water Systems. 2nd ed.

8   Huck, P.M., B.M. Coffey, A. Amirtharajah, and E.J. Bouwer. 2000. Optimizing Filtration
9   in Biological Filters. AWWARF Report 90793. Project #252.

10   Hulsey, R.A. et al. 2004. Evaluation of Ozone and Ultraviolet Light. AWWARF Report
11   91046F. Project #2749.

12   Jacangelo, J.G., C. Gerba, and C.N. Haas. 2002. Inactivation of Waterborne Emerging
13   Pathogens by Selected Disinfectants. AWWARF Report 90886. Project #442. Denver,
14   CO.

15   Kawamura, Susumu. 2000. Integrated Design and Operation of Water Treatment
16   Facilities. 2nd ed. John Wiley & Sons, Inc.

17   Kim, Y., Y. Lee, C.S. Gee, and E. Choi. 1997. Treatment of Taste and Odor Causing
18   Substances in Drinking Water. Water Science and Technology. 35(8): 29-36.

19   LeChevallier, M.W., C.D. Cawthorn, and R.G. Lee. 1988a. Factors Promoting Survival
20   of Bacteria in Chlorinated Water Supplies. Applied and Environmental Microbiology.
21   54(3): 649-654.

22   LeChevallier, M.W., G. Di Giovanni, J.L. Clancy, Z. Bukhari, S. Bukhari, J.S. Rosen, J.
23   Sobrinho, and M.M. Frey. 2002. Source Water Assessment: Variability of Pathogen
24   Concentrations. AwwaRF Report 90906. Project #488.

25   Logsdon, G.S. et al. 2002. Filter Maintenance and Operations Guidance Manual.
26   AWWARF Report 90908. Project #2511.

27   McGuire, M.J., J.L. McLain, and A. Obolensky. 2002. Information Collection Rule Data
28   Analysis. AWWARF Report 90947. Project #2799.

29   McMeen. 2001. Alternate Filtration: Placing New Technology in an Old Regulatory Box.
30   American Water Works Association, Membrane Conference Proceedings.

1   Mullenger, J., G. Ryan, and J. Hearn. 2002. A Water Authority's Experience with
2   HACCP. Water Supply. 2(5-6): 149-155.

3   Mysore, C. et al. 2003. Impact of Water Quality on the Inactivation of Bacterial and Viral
4   Pathogens. AwwaRF Report 90972F. Project #2592.

5   NSF International. 1996. NSF International Environmental Management System
6   Demonstration Project - Final Report.

7   Pennsylvania's Multi State Working Group Pilot. The Effects of ISO 14001
8   Environmental Management Systems on the Environmental and Economic Performance
9   of Organizations. March 27, 1999.

10 Prévost, M.(editor) et al. 2005. Biodegradable Organic Matter in Drinking Water
11 Treatment and Distribution. AWWA.

12 Redaud, J.L. 2005. ISO/TC 224 "Service Activities Relating to Drinking Water Supply
13 Systems and Wastewater Systems - Quality Criteria of the Service and Performance
14 Indicators". ISO. March 31, 2005.

15 Renner, R. 2004. Plumbing the Depths of D.C.'s Drinking Water Crisis. Environmental
16 Science and Technology. 38(12): 224-227.

17 Roig, R. and A. Saponara. 2003. ISO 14001 Environmental Management Systems: A
18 Complete Implementation Guide. ISO.

19 Sorg, T.J. 1988. Methods for Removing Uranium from Drinking Water. Journal of the
20 American Water Works Association, 80(7)

21 Texas Natural Resource Conservation Commission (TNRCC). 2005. Texas Optimization
22 Program (TOP). http://www.tceq.state.tx.us/permitting/water_supply/pdw/swmor/top/

23 U.S. EPA. 1989. National Primary Drinking Water Regulations; Giardia lamblia, Viruses,
24 and Legionella, Maximum Contaminant Levels, and Turbidity, and Heterotrophic
25 Bacteria. (Surface Water Treatment Rule), Final Rule. 43 FR 27486. June 29, 1989.

26 U.S. EPA. 1991. Guidance Manual for Compliance with the Filtration and Disinfection
27 Requirements for Public Water Systems Using Surface Water Sources. Developed by
28 Malcolm Pirnie and HDR. USEPA, Washington, DC. 568 pp.

29 U.S. EPA. 1994. National Primary Drinking Water Regulations: Disinfection and
30 Disinfection Byproducts; Proposed Rule. 59 FR 38668. July 29, 1994.

1   U.S. EPA. 1998a. Handbook: Optimizing Water Treatment Plant Performance Using the
2   Composite Correction Program. EPA 625/6-91/027.

3   U.S. EPA. 1998b. National Primary Drinking Water Regulations: Interim Enhanced
4   Surface Water Treatment Rule; Final Rule. 63 FR 69477. December 16, 1998
5   http://www.epa.gov/safewater/mdbp/ieswtrfr.html

6   U.S. EPA. 1998c. National Primary Drinking Water Regulations: Disinfectants and
7   Disinfection By Products; Final Rule. 63 FR 69389. December 16, 1998.
8   http://www.epa.gov/safewater/mdbp/dbpfr.html

9   U.S. EPA. 1999a. Disinfection Profiling and Benchmarking Guidance Manual. EPA 815-
10 R-99-013.

11 U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-
12 99-014.

13 U.S. EPA. 1999c. Uncovered Finished Water Reservoirs Guidance Manual. EPA 815-R-
14 99-011.

15 U.S. EPA. 1999d. Guidance Manual for Compliance with the Interim Enhanced Surface
16 Water Treatment Rule: Turbidity Provisions. EPA 815-R-99-010.

17 U.S. EPA. 1999e. Unfiltered Systems Guidance Manual.

18 U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance
19 Guidance Manual. EPA 815-R-99-011. August 1999.

20 U.S. EPA. 1999g. Guidance Manual for Conducting Sanitary Surveys of Public Water
21 Systems; Surface Water and Ground Water Under the Direct Influence (GWUDI). EPA
22 815-R-99-016.

23 U.S. EPA. 1999i. Lead and Copper Rule Minor Revision Fact Sheet. EPA 815-F-99-010.

24 U.S. EPA. 2000a. National Primary Drinking Water Regulations: Radionuclides Rule;
25 Final Rule. 65 FR 76707. December 7, 2000.
26 http://www.epa.gov/safewater/rads/radfr.html

27 U.S. EPA. 2000b. National Primary Drinking Water Regulations for Lead and Copper. 65
28 FR 1949. January 12, 2000. http://www.epa.gov/fedrgstr/EPA-
29 WATER/2000/January/Day-12/w3.htm

30 U.S. EPA. 2000c. Lead and Copper Rule: Summary of Revisions. Office of Water. EPA
31 815-R-99-020.

1   U.S. EPA. 2001a. Implementation Guidance for the Stage 1 Disinfectants/Disinfection
2   Byproducts Rule. Office of Water. EPA 816-R-01-012.

3   U.S. EPA. 2001b. State Implementation Guidance for the Lead and Copper Rule Minor
4   Revisions. Office of Water. EPA 816-R-01-021.

5   U.S. EPA. 2001d. National Primary Drinking Water Regulations: Filter Backwash
6   Recycling Rule; Final Rule. 66 FR 31085. June 8, 2001.
7   http://www.epa.gov/safewater/mdbp/fr-fbr.html

8   U.S. EPA. 2001e. National Primary Drinking Water Regulations: Arsenic and
9   Clarifications to Compliance and New Source Contaminants Monitoring . 66 FR 6975.
10   January 22, 2001. http://www.epa.gov/fedrgstr/EPA-WATER/2001/January/Day-
11   22/w1668.htm

12   U.S. EPA. 2001f. Total Coliform Rule: A Quick Reference Guide. EPA 816-F-01-035.
13   November, 2001. http://www.epa.gov/safewater/tcr/pdf/qrg_tcr_v10.pdf

14   U.S. EPA. 2001g. A Small System Guide to the Total Coliform Rule. Office of Water.
15   EPA 816-R-01-017A. http://www.epa.gov/safewater/smallsys/small-tcr.pdf

16   U.S. EPA. 2001k. Stage 1 Disinfectants and Disinfection Byproducts Rule: A Quick
17   Reference Guide. Office of Water. EPA 816-F-01-010. May, 2001.
18   http://www.epa.gov/safewater/mdbp/qrg_st1.pdf

19   U.S. EPA. 2001l. Interim Enhanced Surface Water Treatment Rule: A Quick Reference
20   Guide. Office of Water. EPA 816-F-01-011. May, 2001.
21   http://www.epa.gov/safewater/mdbp/qrg_ieswtr.pdf

22   U.S. EPA. 2001m. Filter Backwash Recycling Rule: A Quick Reference Guide. Office of
23   Water. EPA 816-F-01-019. June 2001. http://www.epa.gov/safewater/mdbp/fbrr_qrg.pdf

24   U.S. EPA. 2001n. Arsenic and Clarifications to Compliance and New Source Monitoring
25   Rule: A Quick Reference Guide. Office of Water. EPA 816-F-01-004. January, 2001.
26   http://www.epa.gov/safewater/arsenic/pdfs/quickguide.pdf

27   U.S. EPA. 2002a. National Primary Drinking Water Regulations: Long Term 1 Enhanced
28   Surface Water Treatment Rule. 67 FR 1811. January 14, 2002.
29   http://www.epa.gov/fedrgstr/EPA-WATER/2002/January/Day-14/w409.htm

30   U.S. EPA. 2002c. Long Term 1 Enhanced Surface Water Treatment Rule: A Quick
31   Reference Guide. Office of Water. EPA 816-F-02-001. January, 2002.
32   http://www.epa.gov/safewater/mdbp/lt1eswtr-quick-ref.pdf

1   U.S. EPA. 2003c. Draft Significant Excursion Guidance Manual. Office of Water. EPA
2   815-D-03-004. July, 2003.

3   U.S. EPA. 2004a. Draft Filter Surveillance Manual (June 2004).

4   U.S. EPA. 2004c. Draft Process Monitoring Manual (July 2004).

5   U.S. EPA. 2004d. National Primary Drinking Water Regulations; Minor Corrections and
6   Clarification to Drinking Water Regulations; National Primary Drinking Water
7   Regulations for Lead and Copper. 69 FR 38850. June 29, 2004.
8   http://www.epa.gov/fedrgstr/EPA-WATER/2004/June/Day-29/w14604.htm

9   U.S. EPA. 2004e. Guidance Manual for Compliance with the Long Term 1 Enhanced
10   Surface Water Treatment Rule: Turbidity Provisions. EPA 816-F-02-001.

11   U.S. EPA. 2004f. The Long Term 1 Enhanced Surface Water Treatment Rule
12   Implementation Guidance. EPA 816-R-04-008.

13   U.S. EPA. 2004g. Lead and Copper Rule: A Quick Reference Guide. Office of Water.
14   EPA 816-F-04-009. March, 2004.

15   U.S. EPA. 2005a. Occurrence Assessment for the Final Stage 2 Disinfectants and
16   Disinfection Byproducts Rule. Prepared by The Cadmus Group, Inc. Contract 68-C-99-
17   206.

18   U.S. EPA. 2005d. Technologies and Costs for the Final Long Term 2 Enhanced Surface
19   Water Treatment Rule and Final Stage 2 Disinfectants and Disinfection Byproducts Rule.
20   EPA 815-R-05-012. December, 2005.

21   U.S. EPA. 2005e. Occurrence and Exposure Assessment for the Long Term 2 Enhanced
22   Surface Water Treatment Rule. EPA-821-R-06-002.

23   U.S. EPA. 2006a. Initial Distribution System Evaluation Guidance Manual for the Final
24   Stage 2 DBPR. Office of Water. EPA 815-B-06-002.

25   U.S. EPA. 2006b. Draft Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2
26   DBPR) Implementation Guidance. Office of Water. EPA 816-R-06-002. June, 2006.

27   U.S. EPA. 2006c. Draft Long Term 2 Enhanced Surface Water Treatment Rule
28   (LT2ESWTR) Implementation Guidance. EPA 816-R-06-006. June, 2006.

29   U.S. EPA. 2006d. Source Water Monitoring Guidance Manual for Public Water Systems
30   for the Long Term 2 Enhanced Surface Water Treatment Rule. Office of Water. EPA
31   815-R-06-005. February, 2006.

Urfer, D., P.M. Huck, S.D.J. Booth, and B.M. Coffey. 1997. Biological Filtration for BOM and Particle Removal: A Critical Review. Journal of American Water Works Association. 89(12):83-98.

Volk, C.J. and M.W. LeChevallier. 2002. Effects of Conventional Treatment on AOC and BDOC Levels. Journal of American Water Works Association. 94(6):112-123.

Westerhoff, G.P., et al. 1998a. The Changing Water Utility: Creative Approaches to Effectiveness and Efficiency. AWWA.

White, G.C. 1992. Handbook of Chlorination and Alternative Disinfectants. Third ed. Van Nostrand Reinhold Co., New York, NY.

White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.

World Health Organization. 2004a. Guidelines for Drinking Water Quality, 3rd Edition. Geneva, Switzerland. World Health Organization.

World Health Organization. 2004b. Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking Water. Edited by M.W. LeChevallier and K.K. Au. ISBN: 1 84339 069 8. Published by IWA Publishing, London, UK.

Wubbena, R.L. 2002a. Strategic Business Planning as a Water Resource Management Tool. AWWARF Report 90905. Project # 2698.

7.1.2   Formation and Control of Chlorinated DBPs

Choi, J. and R. Valentine. 2002. Formation of N-nitrosodimethylamine (NDMA) from reaction of monochloramine: a new disinfection by-product. Water Research. 36: 817-824.

Cowman, G.A., and P.C. Singer. 1994. Effect of Bromide Ion on Haloacetic Acid Speciation Resulting from Chlorination and Chloramination of Humic Extracts. Conference proceedings, AWWA Annual Conference, New York, NY.

George, D.B. et al. 1990. Case Studies of Modified Disinfection Practices for Trihalomethane Control. AWWARF Report 90574. Project #201.

Krasner, S.W. et al. 2003. Case Studies of Modified Treatment Practices for Disinfection By-Product Control. AWWARF Report 90946F. Project #369.

Krasner, S.W., K.M. Reagan, J.G. Jacangelo, N.L. Patania, E.M. Aieta, and K.M. Gramith. 1990. Relationships Between Disinfection By-products and Water Quality

1   Parameters: Implications for Formation and Control. In Proc. AWWA Annual
2   Conference. Denver, Colo.: American Water Works Association.

3   Mitch, W.A., and D.L. Sedlak. 2002. Factors Controlling Nitrosoamine Formation
4   During Wastewater Chlorination. Water Supply. 2(3): 191-198.

5   Najm, I. and R. Rhodes Trussell. 2001. NDMA formation in water and wastewater.
6   Journal of American Water Works Association. 93(2): 92-99.

7   Reckhow, D.A. and P.C. Singer. 1985. Mechanisms of Organic Halide Formation During
8   Fulvic Acid Chlorination and Implications with Respect to Pre-ozonation. Water
9   Chlorination: Environmental Impact and Health Effects. 5: 1229-1257 (Lewis Publishers,
10   Inc., Chelsea, MI, 1985).

11   Routt, J.C. 2004. Lowering DBPs in Combined Systems. Opflow. 30(4): 1-7.

12   Routt, J.C. and N.G. Pizzi 2000. Kentucky-American Water's Cooperative, Step-wise
13   Process of Assisting Two Small Contiguous Systems in Complying with Pending D/DBP
14   Requirements. Proceedings of AWWA Water Quality Technology Conference.

15   Singer, P.C. (Ed.). 1999. Formation and Control of Disinfection By-Products in Drinking
16   Water. AWWA. Denver, CO. 424 pp.

17   Singer, P.C. 1992. Formation and Characterization of Disinfection Byproducts. Presented
18   at the First International Conference on the Safety of Water Disinfection: Balancing
19   Chemical and Microbial Risks.

20   Singer, P.C. and S.D. Chang. 1989. Correlations between trihalomethanes and total
21   organic halides formed during water treatment. Journal of American Water Works
22   Association. 81(8): 61-65.

23   Singer, P.C. et al. 2002. Relative Dominance of HAAs and THMs in Treated Drinking
24   Water. AWWARF Report 90844. Project #339.

25   Speitel, G.E. Jr. and J.M. Symons.1998. Advanced Oxidation/Biodegradation Processes
26   for the Destruction of TOC and Disinfection By-Product Precursors. AWWARF Report
27   #90758. Project #289.

28   Stevens, A.A., C.J. Slocum, D.R. Seeger, and G.G. Robeck. 1976. Chlorination of
29   Organics in Drinking Water. Journal of American Water Works Association. 68(11):615.

30   Stevens, A.A., L.A. Moore. and R.J. Miltner. 1989. Formation and Control of Non-
31   Trihalomethane Byproducts. Journal of American Water Works Association. 81(8): 54.

Summers, R.S., S.M. Hooper, H.M. Shukairy, G. Solarik, and D. Owen. 1996. Assessing DBP yield: uniform formation conditions. Journal of American Water Works Association. 88(6): 80–93.

U.S. EPA. 2001c. Controlling Disinfection By-Products and Microbial Contaminants in Drinking Water. Office of Research and Development. EPA/600/R-01/110.

7.1.3 Corrosion

AWWA. 1993. Initial Monitoring Experiences of Large Water Utilities Under USEPA's Lead and Copper Rule. Sponsored by the WITAF. Denver Colorado.

AWWA. 2004d. Proceedings of Getting the Lead Out: Analysis & Treatment of Elevated Lead Levels in DC's Drinking Water. WQTC.

AWWA. 2005a. Managing Change and Unintended Consequences: Lead and Copper Rule Corrosion Control Treatment

AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.

Burlingame, G.A. and A. Sandvig. 2004. How to Mine Your Lead and Copper Data. Opflow. 30(6):16-19.

Cottis, R.A., S. Turgoose, and R. Newman. 1999. Corrosion Testing Made Easy: Electrochemical Impedance and Noise. National Association of Corrosion Engineers. Houston, TX.

Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Edwards, M., and S. Reiber. 1997. A General Framework for Corrosion Control Based on Utility Experience. AWWARF Report 90712. Project #910.

Edwards, M., and T. Holm. 2001. Role of Phosphate Inhibitors in Mitigating Lead and Copper Corrosion. AWWARF Report 90823 Project #2587.

Edwards, M., J.C. Rushing, S. Kvech, and S. Reiber. 2004. Assessing copper pinhole leaks in residential plumbing. Water Science and Technology. 49(2): 83-90.

Edwards, M., J.F. Ferguson, S. Reiber. 1994. The Pitting Corrosion of Copper. Journal of American Water Works Association. 86(7): 74-91.

Edwards, M., S. Jacobs and D. Dodrill 1999. "Desktop Guidance for Mitigating Pb and Cu Corrosion Byproducts," Journal of the American Water Works Association, 91:5:66-77.

Edwards, M., T.E. Meyer, J. Rehring, J. Ferguson, G. Korshin, and S. Perry. 1996. Role of Inorganic Anions, NOM, and Water Treatment Process in Copper Corrosion. AWWARF Project 90687 Project #831.

Kirmeyer, G.J. 1990. Lead Control Strategies. AWWARF

Kirmeyer, G.J. et al. 2000a. Distribution System Water Quality Changes Following Implementation of Corrosion Control Strategies. AWWARF Report 90764. Project #157.

Kirmeyer, G.J., A.M. Sandvig, G.L. Pierson, and C.H. Neff. 1994. Development of a Pipe Loop Protocol for Lead Control. AWWARF Report 90650 Project #604

Kirmeyer, G.J., B.M. Murphy, A. Sandvig, G. Korshin, B. Shaha, M. Fabbricino, and G. Burlingame. 2004b. Post Optimization of Lead and Copper Control Monitoring Strategies. AWWARF Report 90996F Project #2679

Korshin, G.V. and J.F. Ferguson. 1999. Corrosion and Metal Release for Lead Containing Materials: Influence of NOM. AWWARF Report 90759 Project #182.

Lytle, D.A. & Schock, M.R., 2005. The Formation of Pb(IV) Oxides in Chlorinated Water. Journal of the American Water Works Association, 97:11:102.

Maas, R.P., J.C. Pitch, and A.M. Smith. 2005. Effects of Fluorides and Chloramines on Lead Leaching from Leaded-Brass Surfaces. Asheville Environmental Quality Institute Technical Report #04-137

Marshall, B., J. Rushing, and M. Edwards. 2003. Confirming the role of aluminum solids and chlorine in copper pitting corrosion. In Proceedings of AWWA Annual Conference. Denver CO.

Rushing, J.C., and M. Edwards. 2002. Effect of aluminum solids and chlorine on cold water pitting of copper. Proceedings of AWWA Water Quality Technology Conference.

Sarin, P., et al. 2003. Iron Release from Corroded, Unlined Cast-Iron Pipes. Journal of American Water Works Association. 95(11): 85-96.

Sarin, P., V.L. Snoeyink, J. Bebee, K.K. Jim, M.A. Beckett, W.M. Kriven, J.A. Clement. 2004. Iron Release from Corroded Iron Pipes in Drinking Water Distribution Systems: Effect of Dissolved Oxygen. Water Research. 38: 1259-1269.

Schock, M.R., Wagner, I. & Oliphant, R., 1996 (Second ed.) The Corrosion and Solubility of Lead in Drinking Water. Internal Corrosion of Water Distribution Systems, pp. 131-230. AWWA Research Foundation/TZW, Denver, CO.

Schock, Michael. 1996. Corrosion Inhibitor Applications in Drinking Water Treatment: Conforming to the Lead and Copper Rule. Presented at NACE Corrosion 1996 Conference.

Schock, M.R., 2001. Tetravalent Lead: A Hitherto Unrecognized Control of Tap Water Lead Contamination. In Proc. of the AWWA Water Quality Technology Conference. Denver, Colo.: AWWA.

Schock, M.R. & Giani, R., 2004. Oxidant/Disinfectant Chemistry and Impacts on Lead Corrosion. In Proc. Of the AWWA Water Quality Technology Conference.

Schock, M.R., Scheckel, K.G., DeSantis, M., and Gerke, T.L., 2005. Mode of Occurrence, Treatment and Monitoring Significance of Tetravalent Lead, In Proc. Of the AWWA Water Quality Technology Conference.

U.S. EPA 2002c. Lead and Copper Monitoring and Reporting Guidance for Public Water Systems. Office of Water. EPA 816-R-02-009.

U.S. EPA. 2003d. Revised Guidance Manual for Selecting Lead and Copper Control Strategies. Office of Water. EPA 816-R-03-001. March, 2003.

Veazey, M.V. 2004. New Research May Explain Pinholes in Copper Tubing. Materials Performance. 43(5): 18-22

7.1.4 Source Management

Cooke, G.D. and R.H. Kennedy. 2001. Managing drinking water supplies. Lake and Reservoir Management. 17(3): 157-174.

Cooke, G.D., and R.E. Carlson. 1989. Reservoir Management for Water Quality and THM Precursor Control. AWWARF Report 90569. Project #308.

Effler, S.W. et al. 2005. Origins, Behavior, and a Mechanistic Model for THM Precursors in Lakes and Reservoirs. AWWARF Report 91057F. Project #557.

Knappe, D.R.U. et al. 2004. Algae Detection and Removal Strategies for Drinking Water Treatment Plants. AwwaRF Report 90971. Project #360.

Kornegay, B.H. 2000c. Natural Organic Matter in Drinking Water: Recommendations to Water Utilities. AWWARF Report 90802. Project #2543.

7.1.5   Distribution System Management

AWWA. 1998. Distribution System Requirements for Fire Protection. 3rd edition. AWWA Manual M31. 63 pp.

AWWA. 2001b. Elevated Water Storage Tanks: Maintenance. VHS Video. Denver, CO.

AWWA. 2002b. Unidirectional Flushing. DVD. Denver, CO.

AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.

AWWA. 2003b. Sizing Water Service Lines and Meters. Second Edition. AWWA Manual M22. 112 pp.

AWWA. 2004a. Computer Modeling of Water Distribution Systems. AWWA Manual M32. 160 pp.

AWWA. 2004e. G200-04: Distribution Systems Operation and Management. 16 pp.

AWWA. 2005. Biodegradable Organic Matter in Drinking Water Treatment and Distribution. M. Prevost et al. (editor).

AWWA. 2005b. Distribution System Water Quality Challenges in the 21st Century – A Strategic Guide. MacPhee, M.J. (Editor) 190 pp.

Camper, A.K. and W.L. Jones. 2000. Factors Affecting Microbial Growth in Model Distribution Systems. AWWARF Report 90785. Project #183.

Cesario, A. L. 1995. Modeling, Analysis, and Design of Water Distribution Systems. AWWA. Denver, CO.

Clark, R.M., and W.M. Grayman. 1998. Modeling Water Quality in Drinking Water Distribution Systems. AWWA. Denver, CO. 231 pp.

Escobar, I.C., A.A. Randall, and J. S. Taylor. 2001. Bacterial Growth in Distribution Systems: Effect of Assimilable Organic Carbon and Biodegradable Dissolved Organic Carbon. Environmental Science and Technology. 35(17): 3442-3447.

Grayman, W.M. et al. 2000. Water Quality Modeling of Distribution System Storage Facilities. AWWARF Report 90774. Projct #260.

Haestad Methods. WaterCAD. Water Distribution Modeling & Management Software.

1   Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water
2   Quality. AWWARF Report 90798. Project #357.

3   Lauer, William C. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.
4   1,083 pp.

5   LeChevallier, M.W., C.D. Cawthorn, and R.G. Lee. 1988b. Inactivation of Biofilm
6   Bacteria. Applied and Environmental Microbiology. 54(10):2492-2499.

7   LeChevallier, M.W., C.D. Lowry, and R.G. Lee. 1990. Disinfection of Biofilms in a
8   Model Distribution System. Journal of American Water Works Association. 82(7): 87-99.

9   LeChevallier, M.W., C.D. Lowry, R.G. Lee, and D.L. Gibbon. 1993. Examining the
10   Relationship Between Iron Corrosion and the Disinfection of Biofilm Bacteria. Journal
11   of the American Water Works Association, 85(7)

12   LeChevallier, M.W., N.J. Welch, and D.B. Smith. 1996. Full scale studies of factors
13   related to coliform regrowth in drinking water. Applied and Environmental
14   Microbiology. 62: 2201-2211.

15   Liu, W., H. Wu, Z. Wang, S.L. Ong, J.Y. Hu and W.J. Ng. 2002. Investigation of
16   Assimilable Organic Carbon (AOC) and Bacterial Regrowth in Drinking Water
17   Distribution System. Water Research 36: 891-898.

18   Lowther, E.D. and R.H. Mosher. 1984. Detecting and Eliminating Coliform Regrowth.
19   Proceedings of the AWWA Water Quality Technology Conference, Denver, CO.
20   AWWA. Denver, CO.

21   Martel, Kathy, Gregory Kirmeyer, Amie Hanson, Melita Stevens, Joanne Mullenger, and
22   Daniel Deere. 2006. Application of HACCP for Distribution System Protection.
23   AWWARF Report 91131. Project #2856. Denver, CO.

24   Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO. 900 pp.

25   Najm, I. 2000. Case Studies of the Impacts of Treatment Changes on Biostability in Full-
26   Scale Distribution Systems. AWWARF Report 90816. Project #361.

27   Powell, J. et al. 2004. Predictive Models for Water Quality in Distribution Systems.
28   AWWARF Report 91023F. Project #2865. Denver, CO.

29   Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA.
30   Denver, CO. 85 pp.

31   Snyder, J.K., and AK. Deb. 2002. Impacts of Fireflow on Distribution System Water
32   Quality, Design, and Operation. AWWARF Report 90913. Project #2554.

Taylor, J.S. et al. 2005. Effects of Blending on Distribution System Water Quality.
AWWARF Report 91065F. Project #2702.

Tikkanen, M. et al. 2001. Guidance Manual for Disposal of Chlorinated Water.
AWWARF Report 90863. Project #2513.

U.S. EPA. 1992. Control of Biofilm Growth in Drinking Water Distribution Systems.
Office of Research and Development, EPA 625/R-92/001.

Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition.
AWWA. Denver, CO. 278 pp.

7.1.6   Problem Organisms in Water Treatment

AWWA. 2003c. Problem Organisms in Water: Identification and Treatment (M7), 3rd
edition. American Water Works Association. 155 pages

Belanger, Scott E., D.S. Cherry, J.L. Farris, K.G. Sappington, and J. Cairns, Jr. 1991.
Sensitivity of the Asiatic Clam to Various Biocidal Control Agents. Journal American
Water Works Association. 83(10).

Britton, J.C. and B. Morton. 1982. A dissection guide, field and laboratory manual for the
introduced bivalve Corbicula fluminea. Malacological Review. Suppl. 3:1-82.

Cameron, G.N., J.M. Symons, S.R. Spencer, and J.Y. Ma. 1989. Minimizing THM
Formation During Control of the Asiatic Clam: A Comparison of Biocides. Journal of
American Water Works Association. 81(10):53-62.

Counts, C. L., III. 1986. The zoogeography and history of the invasion of the United
States by Corbicula fluminea (Bivalvia: Corbiculidae). American Malacological Bulletin,
Special Edition No. 2, Proceedings of the Second International Corbicula Symposium.
pp. 7-39.

Lange, C. L., T. M. Short, E. Blake. 1994. Development of Zebra Mussel Control
Strategies for a Coalition of Vermont Water Suppliers on Lake Champlain. Proceedings
of The Fourth International Zebra Mussel Conference, Madison, Wisconsin, March 1994.

Stevenson, B. 1997. Controlling Zebra Mussels at Water Treatment Plant Intakes.
AWWARF Report 90612. Project #614.

Stevenson, B. 1999. Controlling Zebra Mussels at Water Treatment Plant Intakes Part II.
AWWARF Report. Project #821.

1   ### 7.1.7   Presedimentation

2   U.S. EPA. 2003a. Draft LT2ESWTR Toolbox Guidance Manual. Office of Water. EPA
3   815-D-03-009. June, 2003.

4   ### 7.1.8   Enhanced Coagulation and Enhanced Softening

5   Bell, K. et al. 2001. Enhanced and Optimized Coagulation for Particulate and Microbial
6   Removal. AWWARF Report. Project #155.

7   Carlson, K.H., S. Via, B. Bellamy, and M. Carlson. 2000. Secondary Effects of Enhanced
8   Coagulation and Softening. Journal of American Water Works Association. 92(6): 63-75.

9   Chowdhury, Z.K., J.A. Roberson, and D.M. Owen, 1997. "A National Evaluation of
10   Enhanced Coagulation and Enhanced Softening." Proc. AWWA Annual Conference,
11   Atlanta, GA, June 1997.

12   Edwards, M. 1997. Predicting DOC Removal During Enhanced Coagulation. Journal of
13   American Water Works Association. 89(5): 78-89.

14   Hering, J.G., P.Y. Chen, J.A. Wilkie, M. Elimelech, and S. Liang. 1996. Arsenic removal
15   by ferric chloride. Journal of American Water Works Association. 88(4): 155-167.

16   Krasner, S.W. and G. Amy, 1995. Jar-test evaluations of enhanced coagulation. Journal
17   of American Water Works Association. 87(10): 93-107.

18   Lovins, W.A., III, S.J. Duranceau, R.M. Gonzalez, and J.S. Taylor. 2003. Optimized
19   Coagulation Assessment for a Highly Organic Surface Water Supply. Journal of
20   American Water Works Association. 95(10): 94-108.

21   Montgomery Watson Inc. 1998. Palm Beach County Water Utilities Department Water
22   Treatment Plant No. 3 Membrane Softening Facility Operations Manual Final Report.
23   Pages 4-19 to 4-20.

24   Randtke, S.J., and R.C. Hoehn. 1999. Removal of DBP precursors by Enhanced
25   Coagulation and Lime Softening. AWWARF Report 90783. Project #814.

26   Randtke, S.J., C.E. Thiel, M.Y. Liao, and C.N. Yamaya. 1982. Removing Soluble
27   Organic Contaminants by Lime-Softening. Journal of American Water Works
28   Association. 74(4): 192.

29   Scott, K.N., J.F. Green, H.D. Do, and S.J. McLean. 1995. Arsenic Removal by
30   Enhanced Coagulation. Journal of the American Water Works Association 87(4)

1   Shorney, H.L., and S.J. Randtke. 1994. Enhanced Lime Softening for the Removal of
2   Disinfection By-Product Precursors. In Proceedings of the 1994 Annual AWWA
3   Conference. Denver CO.

4   States, S., R. Tomko, M. Scheuring, and L. Casson. 2002. Enhanced coagulation and
5   removal of Cryptosporidium. Journal of American Water Works Association. 94(11): 67-
6   77.

7   Thompson, P.L., and W.L. Paulson 1998. Dewaterability of Alum and Ferric Coagulation
8   Sludges. Journal of American Water Works Association. 90(4): 164-170.

9   U.S. EPA. 1999h. Enhanced Coagulation and Enhanced Precipitative Softening Guidance
10 Manual. EPA 815-R-99-012.

11 U.S. EPA. 2004b. Draft Coagulation Control Manual (July 2004).

12 U.S. EPA. 2005c. A Regulator's Guide to the Management of Radioactive Residuals
13 from Drinking Water Treatment Technologies. USEPA 816-R-05-004.

14 **7.1.9   GAC**

15 American Chemical Society. 1983. Treatment of Water by Granular Activated Carbon.
16 M.J. McGuire and I.H. Suffet (eds). Washington, D.C.

17 Crittenden, J.C. 1989. Prediction of GAC Performance Using Rapid Small-Scale Column
18 Tests. AWWARF Report 90549. Project #230.

19 Klotz, M., P. Werner, and R. Schweisfurth. 1976. Investigations concerning the
20 microbiology of activated carbon filters. Pp. 312-330 in H. Sontheimer, ed. Translation of
21 Reports on Special Problems of Water Technology. Volume 9 Adsorption. Conference
22 held in Karlsruhe, Federal Republic of Germany, 1975. U.S. Environmental Protection
23 Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio. Report No.
24 EPA 600/9-76-030.

25 Leung, K.S., and R.L. Segar. 2000. Adsorption Interactions of S-Triazine Herbicide with
26 Trace Organics in a GAC Filter-Absorber. Presented at the AWWA Conference
27 December, 2000.

28 McTigue, N. and D. Cornwell. 1994. The Hazardous Potential of Activated Carbons
29 Used in Water Treatment. AWWARF Report 90640. Project #620.

30 Najm, I., M. Kennedy, and W. Naylor. 2005. Lignite versus Bituminous GAC for
31 Biofiltration - A Case Study. Journal of American Water Works Association. 97(1): 94-
32 101.

1   Owen, D.M. 1998. Removal of DBP Precursors by GAC Adsorption. AWWARF Report
2   90744. Project #816.

3   Xie, Y., et al. 2004. Haloacetic Acid Removal Using Granular Activated Carbon.
4   AWWARF Report 91041F. Project #2825.

5   **7.1.10 Membranes**

6   Adham, S., et al. 2005. Development of a Microfiltration and Ultrafiltration Knowledge
7   Base. AWWARF Report 91059. Project #2763.

8   Amy, G., M. Clark, and J. Pellegrino. 2001. NOM Rejection by, and Fouling of, NF and
9   UF Membranes. AWWARF Report 90837. Project #390.

10   AWWA. 1999. Reverse Osmosis and Nanofiltration. AWWA Manual M46.

11   Brown, J. and and D. Hugaboom. 2004. Integrating Membrane Treatment in Large Water
12   Utilities. AWWARF Report 91045F. Project #2876.

13   Duranceau, S.J. 2001. Membrane Practices for Water Treatment. AWWA. Denver, CO.

14   Glucina, K., A. Alvarez, and J.M. Laine. 2000. Assessment of an integrated membrane
15   system for surface water treatment. Proceeding of the conference in drinking and
16   industrial water production. 2: 113-122. Italy, October 2000.

17   Laine, J.M., J.G. Jacangelo, E.W. Cummings, K.E. Carns, J. Mallevialle. 1993. Influence
18   of Bromide on Low Pressure Membrane Filtration for Controlling DBPs in Surface
19   Waters. Journal of American Water Works Association. 85(6).

20   Mallevialle, J. et al. 1996. Water Treatment Membrane Processes. AWWARF Report
21   90716. Project #826.

22   Panayides, N. 1999. Operational Procedures of a New 27 MGD Nanofiltration Membrane
23   Water Treatment Plant (WTP No. 9) in South Florida. Palm Beach County Water
24   Utilities Department.

25   Schippers, J.C. et al. 2004. Integrated Membrane Systems. AWWARF Report 90899.
26   Project #264.

27   U.S. Bureau of Reclamation. 1998. The Desalting and Water Treatment Membrane
28   Manual: A Guide to Membranes for Municipal Water Treatment (2nd Edition). Technical
29   Service Center, Water Treatment Engineering and Research, Denver, CO.

30   U.S. EPA. 2005b. Membrane Filtration Guidance Manual. Office of Water. EPA 815-R-
31   06-009. November, 2005.

1   **7.1.11 Riverbank Filtration**

2   Gollnitz, W.D., J.L.Clancy, J. B. McEwen, and S. C. Garner. 2005. Riverbank Filtration
3   for IESWTR Compliance. 2005. Journal of American Water Works Association.
4   97(12):64-76.

5   Julich, W. and J. Schubert (eds.). Proceedings of International Riverbank Filtration
6   Conference, Nov. 2-4, Duesseldorf. International Arbeitgemeinschaft der Wasserwerke
7   im Rheineinzugsgebiet, Amsterdam.

8   Ray, C. (ed.). 2001. Riverbank Filtration: Understanding Contaminant Biogeochemistry
9   and Pathogen Removal.NATO Science Series IV. Earth and Environmental Sciences -
10   Vol. 14. Kluwer Academic Publishers.

11   Wang, J., S. Hubbs, and R. Song. 2002. Evaluation of Riverbank Filtration as a Drinking
12   Water Treatment Process. AWWARF Report 90922. Project #2622.

13   **7.1.12 Chloramines**

14   Arber, R., M.A. Speed, and F. Scully. 1985. Significant Findings Related to Formation of
15   Chlrinated Organics, in the Presence of Chloramines. In: Water Chlorination:
16   Environmental Impact and Health Effects, Vol. 7. Edited by R.L. Jolley, R.J. Bull, W.P.
17   Davis, S. Katz, M.H. Roberts, and V.A. Jacobs. Chelsea, MI: Lewis Publishers.

18   AWWA. 2004b. Converting Distribution Systems from Chlorine to Chloramines. DVD.
19   Denver, CO.

20   Bonds, R.W. 2004. Effect of Chloramines on Ductile-Iron Pipe Gaskets of Various
21   Eslastomer Compounds. Journal of American Water Works Association. 96(4): 153-160.

22   Gell, R. and J. Bromka. 2003. Successful Application of Chloramines to Manage
23   Disinfection By-Products. New York State Section AWWA. September 2003. Published
24   by O'Brien and Gere.

25   Gianatasio, J.M. 1985. Experience at Tampa, Florida, Using Combined Chlorine to
26   Control THM Production. Paper presented at the North Carolina AWWA/WPLC Joint
27   Technical Conference, November 13, at Charlotte NC.

28   Harms, L.L. and C. Owen. 2004. Draft. A Guide for the Implementation and Use of
29   Chloramines. AWWARF Report 91018F. Project #2847.

30   Harrington, G.W., D.R. Noguera, C.C. Bone, A.I. Kandou, P.S. Oldenburg, J.M. Regan,
31   and D. Van Hoven. 2003. Ammonia from Chloramine Decay: Effects on Distribution
32   System Nitrification. AWWARF Report 90949. Project #553.

1   Jacangelo, J.G., V.P. Olivieri, and K. Kawata. 1987. Mechanism of Inactivation of
2   Microorganisms by Combined Chlorine. AWWA, Denver, CO.

3   Kirmeyer, G.J. et al. 1995. Nitrification Occurrence and Control in Chloraminated Water
4   Systems. AWWARF Report 90669. Project #710.

5   Kirmeyer, G.J. et al. 2004a. Update of Optimizing Chloramine Treatment. AWWARF
6   Report 90993. Project #2760.

7   Krasner, S.W., and S.E. Barrett. 1985. Aroma and Flavor Characteristics of Free Chlorine
8   and Chloramines. In Proc. Of the Twelfth Annual AWWA Water Quality Technology
9   Conference. AWWA Denver, CO.

10   McGuire, M.J., M.S. Pearthree, N.K. Blute, K.F. Arnold, and T. Hoogerwerf. 2006.
11   Nitrification Control by Chlorite Ion at Pilot Scale. Journal of the American Water
12   Works Association, 98(1):95-105

13   McGuire, M.J., N.I. Lieu, and M.S. Pearthree. 1999. Using chlorite ion to control
14   nitrification. Journal of American Water Works Association. 91(10): 52-61.

15   Means, E.G., K.N. Scott, M.L. Lee, and R.W. Wolfe. 1986. Effects of Chlorine and
16   Ammonia Application Points on Bactericidal Efficiency. Journal of American Water
17   Works Association. 78(1): 62-69.

18   Ollos, P.J., P.M. Huck, R.M. Slawson. 2003. Factors Affecting Biofilm Accumulation in
19   Model Distribution Systems. Journal of American Water Works Association. 94(1).

20   Reiber, S. 1991. Corrosion Effects by Chloramines. AWWARF Denver, CO.

21   Reiber, S. 1993. Chloramine Effects on Distribution System Materials. AWWARF
22   Report 90624. Project #508.

23   Skadsen, J. 1993. Nitrification in a Distribution System. Journal of American Water
24   Works Association. 85(7): 95-103.

25   Speitel, G.E. Jr. et al. 2004. Disinfection By-Product Formation and Control During
26   Chloramination. AWWARF Report 91040F. Project #2677.

27   Symons, J.M. et al. 1998. Factors Affecting DBP Formation During Chloramination.
28   AWWARF Report 90728. Project #803.

29   Tokuno, S. 1999. Granulated Activated Carbon Filtration and Chloramine. Water
30   Engineering Management, 146(1):16-21

1   Uchida, M. and A. Okuwaki. 1999. Dissolution Behavior of Lead Plates in Aqueous
2   Nitrate Solutions. Corrosion Science. 41:1977

3   Valentine, R.L. 1998. Chloramine Decomposition in Distribution System and Model
4   Waters. AWWARF Report 90721. Project #937.

5   Wilczak, A. L. Hoover, and H.H. Lai. 2003. Effects of Treatment Changes on
6   Chloramine Demand and Decay. Journal of the American Water Works Association.
7   95(7):94-107

8   Wilczak, A., J.G. Jacangelo, J.P. Marcinko, L.H. Odell, G.J. Kirmeyer, and R.L. Wolfe.
9   1996. Occurrence of Nitrification in Chloraminated Distribution Systems. Journal of
10   American Water Works Association. 88(7): 74-85.

11   Wolfe, R.L. 1990. Ammonia-Oxidizing Bacteria in a Chloraminated Distribution System:
12   Seasonal Occurrence, Distribution, and Disinfection Resistance. Applied and
13   Environmental Microbiology. 56: 541.

14   Wolfe. R.L., E.G. Means, M.K. Davis, and S.E. Barrett. 1988. Biological Nitrification in
15   Covered Reservoirs Containing Chloraminated Water. Journal of American Water Works
16   Association. 80(9): 109-114.

17   **7.1.13 Ozone**

18   AWWARF and Compagnie Generale des Eaux. 1992. Ozone in Water Treatment:
19   Application and Engineering. AWWARF Report. Project #421.

20   Becker, W.C. et al. 1996. Optimizing Ozonation for Turbidity and Organics (TOC)
21   Removal by Coagulation and Filtration. AWWARF Report 90703. Project #934.

22   Carlson, K.H. and G.L. Amy. 2001. Ozone and biofiltration optimization for multiple
23   objectives. Journal of American Water Works Association. 93(1): 88-98.

24   Escobar, I.C. and A.A. Randall. 2001. Case study: Ozonation and distribution system
25   biostability. Journal of American Water Works Association. 93(10): 77-89.

26   Galey, C. et al. 2001. Controlling bromate formation. Journal of American Water Works
27   Association. 93(8): 105-115.

28   Kennedy, R.M. and M.E. Richardson. 2004. Ozone and Biofiltration, An Improved Water
29   Quality at Wilmington. PowerPoint Presentation.

1   LeChevallier, M.W., W.C. Becker, P. Schorr, and R.G. Lee. 1992. Evaluating the
2   Performance of Biologically Active Rapid Sand Filters. Journal of American Water
3   Works Association. 84(4): 136.

4   National Research Council. 2000. Identifying Future Drinking Water Contaminants.
5   National Academy Press. Washington, D.C.

6   Price, M.L. et al. 1994. Ozone and Biological Treatment for DBP Control and Biological
7   Stability. AWWARF Report 90649. Project #504.

8   Reckhow, D.A. 1999. Control of Disinfection Byproduct Formation Using Ozone. In
9   Singer, P.C. (Ed) Formation and Control of Disinfection By-Products in Drinking Water.
10 pp. 179-204 AWWA, Denver, CO.

11 Reckhow, D.A. J.K. Edzwald, and J.E. Tobiason. 1993. Ozone as an Aid to Coagulation
12 and Filtration. AWWARF Report 90643. Project #403.

13 Stolarik, G., and J.D. Christie. 1997. A Decade of Ozonation in Los Angeles. Conference
14 proceedings, IOA Pan American Group Annual Conference, Lake Tahoe, NV.

15 Urfer, D. et al. 1999. Modeling enhanced coagulation to improve ozone disinfection.
16 Journal of American Water Works Association. 91(3): 59-73.

17 Van der Kooij, D. 1997. Bacterial Nutrients and Biofilm Formation Potential within
18 Drinking Water Distribution Systems. Conference Proceedings, AWWA Water Quality
19 Technology Conference.

20 Westerhoff, G.P., et al. 1998b. NOM's role in bromine and bromate formation during
21 ozonation. Journal of American Water Works Association. 90(2): 82-94.

22 Williams, M.D., B.M. Coffey, and S.W. Krasner, 2003. Evaluation of pH and Ammonia
23 for Controlling Bromate During Cryptosporidium Disinfection. Journal of American
24 Water Works Association. 95(10): 82-93.

25 Zhou, P. and J. Neemann. 2005. Use of Chlorine Dioxide and Ozone for Control of
26 Disinfection By-Products. AWWARF Report 90981F. Project #2742.

27 **7.1.14 Ultraviolet Light**

28 Ballester, N.A. and J.P. Malley, Jr. 2004. Sequential Disinfection of Adenovirus Type 2
29 with UV-Chlorine-Chloramine. Journal of American Water Works Association.
30 96(10):97-103.

1   Bukhari, Z., T.M. Hargy, J.R. Bolton, B. Dussert, and J.L. Clancy. 1999. Medium-
2   Pressure UV for Oocyst Inactivation. Journal of American Water Works Association.
3   91(3): 86-94.

4   Clancy, J.L. et al. 2000. Using UV to inactivate Cryptosporidium. Journal of American
5   Water Works Association. 92(9): 97-104.

6   Cotton, C. et al. 2006. Integrating UV Disinfection Into Existing Water Treatment Plants.
7   AWWARF Report 91086. Project #2861.

8   Cotton, C.A., D.M. Owen, G.C. Cline, and T.P. Brodeur. 2001. UV disinfection costs for
9   inactivating Cryptosporidium. Journal of American Water Works Association. 93(6): 82-
10   94.

11   Crozes, G. 2001. Practical Aspects of UV Disinfection. AWWARF Report 90875. Project
12   #2623.

13   Gagnon, G.A., T.S. Dykstra, K.C. O'Leary, R.C. Andrews, C. Chauret and C. Volk.
14   2004. Impact of UV Disinfection on Biological Stability. AWWARF Report 90999F.
15   Project #2723.

16   Mackey, E.D., J. Malley, Jr., R.S. Cushing, M. Janex-Habibi, N. Picard, and J. Laine,
17   2001. Bridging Pilot-Scale Testing to Full-Scale Design of UV Disinfection Systems.
18   AWWARF Report 90991. Project #2593.

19   Malley, J.P. et al. 2001. Full Scale Implimention of UV in Groundwater Disinfection
20   Systems. AWWARF Report 90860. Project #474.

21   Malley, J.P. Jr. et al. 2004. Inactivation of Pathogens with Innovative UV Technologies.
22   AWWARF Report 91024. Project #2593.

23   Mofidi, A.A. et al. 2001. Disinfection of Cryptosporidium parvum with polychromatic
24   UV light. Journal of American Water Works Association. 93(6): 95-109.

25   NWRI and AWWARF. 2000. Ultraviolet Disinfection Guidelines for Drinking Water and
26   Water Reuse. AWWARF Report. Project #2674.

27   Shaw, J.P., J.P. Malley Jr., and S. Willoughby. 2000. Effects of UV irradiation on organic
28   matter. Journal of American Water Works Association. 92(4): 157-167.

29   U.S. EPA. 2003b. Draft Ultraviolet Disinfection Guidance Manual. Office of Water. EPA
30   815-D-03-007. June, 2003.

1   **7.1.15 Chlorine Dioxide**

2   Andrews, R.C. et al. 2005. Impact of Chlorine Dioxide on Transmission, Treatment, and
3   Distribution System Performance. AWWARF Report 91082. Project #2843.

4   Dietrich, A.M. and R.C. Hoehn. 1991. Taste-and-Odor Problems Associated with
5   Chlorine Dioxide. AWWARF Report 90589. Project #405.

6   Gallagher, D.L., R.C. Hoehn, and A.M. Dietrich. 1994. Sources, Occurrence, and Control
7   of Chlorine Dioxide By-Product Residuals in Drinking Water. AWWARF Report 90656.
8   Project #611.

9   Gates, D. 1997. The Chlorine Dioxide Handbook. AWWA. Denver, CO. 177 pp.

10   Gordon, G. 2001. Is all chlorine dioxide created equal? Journal of American Water
11   Works Association. 93(4): 163-174.

12   Hoehn, R.C. 1993. Chlorine Dioxide Use in Water Treatment: Key Issues Proceedings,
13   2nd International Symposium, Chlorine Dioxide and Drinking Water Issues. Houston,
14   TX. pp. 1-14.

15   Hoehn, R.C., A.M. Dietrich, W.S., Farmer, M.P. Orr, R.G. Lee, E.M. Aieta, D.W. Wood
16   III, and G. Gordon. 1990. Household Odors Associated with the Use of Chlorine Dioxide.
17   Journal of American Water Works Association. 82(4):166-172.

18   Volk, C.J., R. Hofmann, C. Chauret, G.A. Gagnon, G. Ranger, and R.C. Andrews. 2002.
19   Implementation of chlorine dioxide disinfection: Effects of the treatment change on
20   drinking water quality in a full-scale distribution system. Journal of Environmental
21   Engineering and Science. 1: 323-330.

22   Williams, M.D., B.M. Coffey, and S.W. Krasner, 2003. Evaluation of pH and Ammonia
23   for Controlling Bromate During Cryptosporidium Disinfection. Journal of American
24   Water Works Association. 95(10): 82-93.

25   Zhou, P. and J. Neemann. 2005. Use of Chlorine Dioxide and Ozone for Control of
26   Disinfection By-Products. AWWARF Report 90981F. Project #2742.

27   **7.1.16 Tools for Gathering More Information**

28   Advantica. SynerGEE Water. Advanced water distribution analysis.
29   http://www.advantica.biz/Default.aspx?page=321

30   American Public Heath Association (APHA), AWWA, and Water Environment
31   Federation (WEF). 1998. Standard Methods for the Examination of Water and
32   Wastewater, 20th Edition. 220 pp.

1   ASTM D2688-83 Method B. 1983a. Standard Test Methods for the Corrosivity of
2   Water in the Absence of Heat Transfer (Weight Loss Protocol). American Society for
3   Testing and Materials. Philadelphia, PA.

4   ASTM D2688-83 Method C. 1983b. Standard Test Methods for the Corrosivity of
5   Water in the Absence of Heat Transfer (Machined Nipple Test). American Society for
6   Testing and Materials. Philadelphia, PA.

7   ASTM D934-80(2003). 2003. Standard Practices for Identification of Crystalline
8   Compounds in Water Formed Deposits by X-Ray Diffraction. American Society for
9   Testing and Materials. Philadelphia, PA.

10   ASTM G1-81. 1981. Recommended Practise for Preparing, Cleaning and Evaluating
11   Corrosion Test Specimens. American Society for Testing and Materials. Philadelphia,
12   PA.

13   ASTM G46-76. 1976. Recommended Practise for the Examination and Evaluation of
14   Pitting Type Corrosion. American Society for Testing and Materials. Philadelphia, PA.

15   AWWA. 2001a. The Rothberg, Tamburini & Winsor Blending Application Package 4.0.
16   AWWA Catalog Number 53042.

17   AWWARF. 2000. Consumer Attitude Survey Update. AWWARF Report 394. Project
18   #394.

19   AWWARF. 2003. Public Involvement Strategies on the Web. Interactive tool that builds
20   on AWWARF Report.
21   http://www.awwarf.org/research/TopicsAndProjects/Resources/webTools/ch2m/default.h
22   tml.

23   Brereton, J.A. and D.S. Mavinic. 2002. Field and material-specific simulated distribution
24   system testing as aids to understanding trihalomethane formation in distribution systems.
25   Canadian Journal of Civil Engineering. 29(1): 17-26.

26   Burlingame, G.A., J.J. Muldowney, R.E. Maddrey. 1992. Cucumber Flavor in
27   Philadelphia's Drinking Water. Journal of American Water Works Association. 84(8).

28   CH2M Hill. 1995. Public Involvement Strategies: A Manager's Handbook. AWWARF
29   Report 90694. Project # 918.

30   Colbourne, J. 2001. Tools and Methods to Effectively Measure Customer Perceptions.
31   AWWARF Report 90856. Project #466.

1   Crittenden, J.C., J.K. Berrigan, and D.W. Hand. 1986. Design of Rapid Small-Scale
2   Adsorption Tests for a Constant Diffusivity. Journal Water Pollution Control Federation.
3   Vol. 58, No. 4, pp. 312-319.

4   Dentel, S.K. et al. 1989. Procedures Manual for Polymer Selection in Water Treatment
5   Plants. AWWARF Report 90553. Project #209.

6   Dietrich, A.M. 2004. Practical Taste-and-Odor Methods for Routine Operations:
7   Decision Tree. AWWARF Report 91019. Project #467.

8   Edwards, M., S.H. Reiber. 1997. Predicting Pb and Cu corrosion by-product release using
9   CORRODE software. AWWARF Report 90712.

10   Emmert, G. et al. 2004. Methods for Real-Time Measurement of THMs and HAAs in
11   Distribution Systems. AWWARF Report 91003F. Project #2873.

12   Giani, R., M. Edwards, C. Chung, and J. Wujek. 2004. Lead Profiling Methodologies
13   and Results. Presented at Getting the Lead Out: Analysis & Treatment of Elevated Lead
14   Levels in DC's Drinking Water at the 2004 AWWA WQTC.

15   Grayman, W.M., R.A. Deininger, and R.M. Males. 2001. Design of Early Warning and
16   Predictive Source-Water Monitoring Systems. AWWARF Report 90878. Project #2527.

17   Hecht, P.M., and E.A. Turner. 2004. Washington Aqueduct Desktop & Flow-Through
18   Study. Presented at Getting the Lead Out: Analysis & Treatment of Elevated Lead
19   Levels in DC's Drinking Water at the 2004 AWWA WQTC.

20   Khiari, D., S. Barrett, R. Chinn, A. Bruchet, P. Piriou, L. Matia, F. Ventura, I. Suffet, T.
21   Gittelman, and P. Luitweiler. 2002. Distribution Generated Taste-and-Odor Phenomena.
22   AwwaRF Report 90897. Project # 365.

23   Kirmeyer, G. 2002. Guidance Manual for Monitoring Distribution System Water Quality.
24   AWWARF Report 90882. Project #2522.

25   Koch, B., S.W. Krasner, M.J. Sclimenti, and W.K. Schimpff. 1991. Predicting the
26   formation of DBPs by the simulated distribution system. Journal of American Water
27   Works Association. 83(10): 62–70.

28   Lauer, B. 2001. Self-Assessment for Treatment Plant Optimization, International Edition.
29   AWWA Publication. 256 pp.

30   McGuire, M., et al. 2004. Water Utility Self-Assessment for the Management of
31   Aesthetic Issues. AWWARF Report 90978F. Project #2777.

1   Nero, W. et al. 2001. Public Involvement . . . Making It Work. AWWARF Report 90865.
2   Project #2526.

3   Olstein, M.A. 2001. Best Practices for a Continually Improving Customer Responsive
4   Organization. AWWARF Report 90868. Project #2525.

5   Raucher, R. et al. 2005. The Value of Water: Concepts, Estimates, and Applications for
6   Water Managers. AwwaRF Report 91068F. Project #2855.

7   Renner, R.C. and B.A. Hegg. 1997. Self-Assessment Guide for Surface Water Treatment
8   Plant Optimization. AWWARF Report 90736. Project #274.

9   Rettie, M. et al. 2005. Effective Practices to Select, Acquire, and Implement a Utility
10   CIS. AWWARF Report 91071. Project # 3007.

11   Tatham, C., E. Tatham, and J. Mobley. 2004. Customer Attitudes, Behavior and the
12   Impact of Communications Efforts. AWWARF Report 90975. Project #2613.

13   U.S. Bureau of Reclamation and I. Moch & Associates. 2003. WTCost©. Development
14   of program sponsored by the American Membrane Technology Association.

15   U.S. EPA. 2001h. Water Treatment Plant Model (Version 2.0).

16   U.S. EPA. 2001i. The Surface Water Analytical Tool (Version 1.1). March 20, 2001.

17   U.S. EPA. 2001j. 1999 Drinking Water Infrastructure Needs Survey: Modeling the Cost
18   of Infrastructure. Office of Water. EPA 816-R-01-005.

19   U.S. EPA. 2002b. EPANET 2.0. http://www.epa.gov/ORD/NRMRL/wswrd/epanet.html

20   Wesner, G.M. Copyright 1994-2000. W/W Costs, Windows Version 3.0.

21

22   ## 7.2   References Organized Alphabetically

23   Adham, S., et al. 2005. Development of a Microfiltration and Ultrafiltration Knowledge
24   Base. AWWARF Report 91059. Project #2763.

25   Advantica. SynerGEE Water. Advanced water distribution analysis.
26   http://www.advantica.biz/Default.aspx?page=321

27   American Chemical Society. 1983. Treatment of Water by Granular Activated Carbon.
28   M.J. McGuire and I.H. Suffet (eds). Washington, D.C.

1   American Public Heath Association (APHA), AWWA, and Water Environment
2   Federation (WEF). 1998. Standard Methods for the Examination of Water and
3   Wastewater, 20th Edition. 220 pp.

4   Amy, G., M. Clark, and J. Pellegrino. 2001. NOM Rejection by, and Fouling of, NF and
5   UF Membranes. AWWARF Report 90837. Project #390.

6   Andrews, R.C. et al. 2005. Impact of Chlorine Dioxide on Transmission, Treatment, and
7   Distribution System Performance. AWWARF Report 91082. Project #2843.

8   Angers, J. 2001. Question of the Month: Which Disinfectant Will Work Best for Us?
9   Opflow. 27(5): 6-7, 22.

10   Arber, R., M.A. Speed, and F. Scully. 1985. Significant Findings Related to Formation of
11   Chlrinated Organics, in the Presence of Chloramines. In: Water Chlorination:
12   Environmental Impact and Health Effects, Vol. 7. Edited by R.L. Jolley, R.J. Bull, W.P.
13   Davis, S. Katz, M.H. Roberts, and V.A. Jacobs. Chelsea, MI: Lewis Publishers.

14   ASTM D2688-83 Method B. 1983a. Standard Test Methods for the Corrosivity of
15   Water in the Absence of Heat Transfer (Weight Loss Protocol). American Society for
16   Testing and Materials. Philadelphia, PA.

17   ASTM D2688-83 Method C. 1983b. Standard Test Methods for the Corrosivity of
18   Water in the Absence of Heat Transfer (Machined Nipple Test). American Society for
19   Testing and Materials. Philadelphia, PA.

20   ASTM D934-80(2003). 2003. Standard Practices for Identification of Crystalline
21   Compounds in Water Formed Deposits by X-Ray Diffraction. American Society for
22   Testing and Materials. Philadelphia, PA.

23   ASTM G1-81. 1981. Recommended Practise for Preparing, Cleaning and Evaluating
24   Corrosion Test Specimens. American Society for Testing and Materials. Philadelphia,
25   PA.

26   ASTM G46-76. 1976. Recommended Practise for the Examination and Evaluation of
27   Pitting Type Corrosion. American Society for Testing and Materials. Philadelphia, PA.

28   AWWA. 1990. Water Quality and Treatment. F.W. Pontius (editor). McGraw-Hill, New
29   York, NY.

30   AWWA 1993. Initial Monitoring Experiences of Large Water Utilities Under USEPA's
31   Lead and Copper Rule. Sponsored by the WITAF. Denver Colorado.

1   AWWA. 1998. Distribution System Requirements for Fire Protection. 3rd edition.
2   AWWA Manual M31. 63 pp.

3   AWWA. 1999. Reverse Osmosis and Nanofiltration. AWWA Manual M46.

4   AWWA. 1999c. Water Quality and Treatment: A Handbook of Community Water
5   Supplies. Fifth Edition. Letterman, R.D. (editor). McGraw-Hill

6   AWWA. 1999d. Design and Construction of Small Water Systems, Second Edition. 228
7   pp.

8   AWWA. 1999e. Hydraulic Design Handbook. Mays, L.W.(editor). McGraw-Hill.

9   AWWA. 2000. Operational Control of Coagulation and Filtration Processes. 2nd Edition.
10   AWWA Manual M37. pp. 1-34.

11   AWWA. 2001a. The Rothberg, Tamburini & Winsor Blending Application Package 4.0.
12   AWWA Catalog Number 53042.

13   AWWA. 2001b. Elevated Water Storage Tanks: Maintenance. VHS Video. Denver, CO.

14   AWWA. 2002b. Unidirectional Flushing. DVD. Denver, CO.

15   AWWA. 2003a. Principles and Practices of Water Supply Operations: Water
16   Transmission and Distribution, Third Edition. 553 pp.

17   AWWA. 2003b. Sizing Water Service Lines and Meters. Second Edition. AWWA
18   Manual M22. 112 pp.

19   AWWA. 2003c. Problem Organisms in Water: Identification and Treatment (M7), 3rd
20   edition. American Water Works Association. 155 pages

21   AWWA. 2004a. Computer Modeling of Water Distribution Systems. AWWA Manual
22   M32. 160 pp.

23   AWWA. 2004b. Converting Distribution Systems from Chlorine to Chloramines. DVD.
24   Denver, CO.

25   AWWA. 2004d. Proceedings of Getting the Lead Out: Analysis & Treatment of Elevated
26   Lead Levels in DC's Drinking Water. WQTC.

27   AWWA. 2004e. G200-04: Distribution Systems Operation and Management. 16 pp.

AWWA. 2005. Biodegradable Organic Matter in Drinking Water Treatment and Distribution. M. Prevost et al. (editor).

AWWA. 2005a. Managing Change and Unintended Consequences: Lead and Copper Rule Corrosion Control Treatment

AWWA. 2005b. Distribution System Water Quality Challenges in the 21st Century – A Strategic Guide. MacPhee, M.J. (Editor) 190 pp.

AWWARF and Compagnie Generale des Eaux. 1992. Ozone in Water Treatment: Application and Engineering. AWWARF Report. Project #421.

AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.

AWWARF and Lyonnaise des Eaux. 1995. Advances in Taste and Odor Treatment and Control. AWWARF Report 90610. Project #629.

AWWARF. 2000. Consumer Attitude Survey Update. AWWARF Report 394. Project #394.

AWWARF. 2003. Public Involvement Strategies on the Web. Interactive tool that builds on AWWARF Report. http://www.awwarf.org/research/TopicsAndProjects/Resources/webTools/ch2m/default.html.

Ballester, N.A. and J.P. Malley, Jr. 2004. Sequential Disinfection of Adenovirus Type 2 with UV-Chlorine-Chloramine. Journal of American Water Works Association. 96(10):97-103.

Becker, W.C. et al. 1996. Optimizing Ozonation for Turbidity and Organics (TOC) Removal by Coagulation and Filtration. AWWARF Report 90703. Project #934.

Becker, W.C., K. Au, C.R. O'Melia, and J.S. Young, Jr. 2004. Using Oxidants to Enhance Filter Performance. AWWARF Report 90998. Project #2725.

Belanger, Scott E., D.S. Cherry, J.L. Farris, K.G. Sappington, and J. Cairns, Jr. 1991. Sensitivity of the Asiatic Clam to Various Biocidal Control Agents. Journal American Water Works Association. 83(10).

Bell, K. et al. 2001. Enhanced and Optimized Coagulation for Particulate and Microbial Removal. AWWARF Report. Project #155.

1   Bonds, R.W. 2004. Effect of Chloramines on Ductile-Iron Pipe Gaskets of Various
2   Eslastomer Compounds. Journal of American Water Works Association. 96(4): 153-160.

3   Brereton, J.A. and D.S. Mavinic. 2002. Field and material-specific simulated distribution
4   system testing as aids to understanding trihalomethane formation in distribution systems.
5   Canadian Journal of Civil Engineering. 29(1): 17-26.

6   Britton, J.C. and B. Morton. 1982. A dissection guide, field and laboratory manual for the
7   introduced bivalve Corbicula fluminea. Malacological Review. Suppl. 3:1-82.

8   Brown, J. and and D. Hugaboom. 2004. Integrating Membrane Treatment in Large Water
9   Utilities. AWWARF Report 91045F. Project #2876.

10   Bukhari, Z., T.M. Hargy, J.R. Bolton, B. Dussert, and J.L. Clancy. 1999. Medium-
11   Pressure UV for Oocyst Inactivation. Journal of American Water Works Association.
12   91(3): 86-94.

13   Burlingame, G.A. and A. Sandvig. 2004. How to Mine Your Lead and Copper Data.
14   Opflow. 30(6):16-19.

15   Burlingame, G.A., J.J. Muldowney, R.E. Maddrey. 1992. Cucumber Flavor in
16   Philadelphia's Drinking Water. Journal of American Water Works Association. 84(8).

17   Cameron, G.N., J.M. Symons, S.R. Spencer, and J.Y. Ma. 1989. Minimizing THM
18   Formation During Control of the Asiatic Clam: A Comparison of Biocides. Journal of
19   American Water Works Association. 81(10):53-62.

20   Camper, A.K. and W.L. Jones. 2000. Factors Affecting Microbial Growth in Model
21   Distribution Systems. AWWARF Report 90785. Project #183.

22   Carlson, K.H. and G.L. Amy. 2001. Ozone and biofiltration optimization for multiple
23   objectives. Journal of American Water Works Association. 93(1): 88-98.

24   Carlson, K.H., S. Via, B. Bellamy, and M. Carlson. 2000. Secondary Effects of Enhanced
25   Coagulation and Softening. Journal of American Water Works Association. 92(6): 63-75.

26   Cesario, A. L. 1995. Modeling, Analysis, and Design of Water Distribution Systems.
27   AWWA. Denver, CO.

28   CH2M Hill. 1995. Public Involvement Strategies: A Manager's Handbook. AWWARF
29   Report 90694. Project # 918.

1   Choi, J. and R. Valentine. 2002. Formation of N-nitrosodimethylamine (NDMA) from
2   reaction of monochloramine: a new disinfection by-product. Water Research. 36: 817-
3   824.

4   Chowdhury, Z.K., J.A. Roberson, and D.M. Owen, 1997. "A National Evaluation of
5   Enhanced Coagulation and Enhanced Softening." Proc. AWWA Annual Conference,
6   Atlanta, GA, June 1997.

7   Clancy, J.L. et al. 2000. Using UV to inactivate Cryptosporidium. Journal of American
8   Water Works Association. 92(9): 97-104.

9   Clark, R.M., and W.M. Grayman. 1998. Modeling Water Quality in Drinking Water
10 Distribution Systems. AWWA. Denver, CO. 231 pp.

11 Colbourne, J. 2001. Tools and Methods to Effectively Measure Customer Perceptions.
12 AWWARF Report 90856. Project #466.

13 Connell, G. 1996. The Chlorination/Chloramination Handbook. AWWA. Denver, CO.
14 174 pp.

15 Cooke, G.D. and R.H. Kennedy. 2001. Managing drinking water supplies. Lake and
16 Reservoir Management. 17(3): 157-174.

17 Cooke, G.D., and R.E. Carlson. 1989. Reservoir Management for Water Quality and
18 THM Precursor Control. AWWARF Report 90569. Project #308.

19 Cottis, R.A., S. Turgoose, and R. Newman. 1999. Corrosion Testing Made Easy:
20 Electrochemical Impedance and Noise. National Association of Corrosion Engineers.
21 Houston, TX.

22 Cotton, C. et al. 2006. Integrating UV Disinfection Into Existing Water Treatment Plants.
23 AWWARF Report 91086. Project #2861.

24 Cotton, C.A., D.M. Owen, G.C. Cline, and T.P. Brodeur. 2001. UV disinfection costs for
25 inactivating Cryptosporidium. Journal of American Water Works Association. 93(6): 82-
26 94.

27 Counts, C. L., III. 1986. The zoogeography and history of the invasion of the United
28 States by Corbicula fluminea (Bivalvia: Corbiculidae). American Malacological Bulletin,
29 Special Edition No. 2, Proceedings of the Second International Corbicula Symposium.
30 pp. 7-39.

Cowman, G.A., and P.C. Singer. 1994. Effect of Bromide Ion on Haloacetic Acid Speciation Resulting from Chlorination and Chloramination of Humic Extracts. Conference proceedings, AWWA Annual Conference, New York, NY.

Crittenden, J.C. 1989. Prediction of GAC Performance Using Rapid Small-Scale Column Tests. AWWARF Report 90549. Project #230.

Crittenden, J.C., J.K. Berrigan, and D.W. Hand. 1986. Design of Rapid Small-Scale Adsorption Tests for a Constant Diffusivity. Journal Water Pollution Control Federation. Vol. 58, No. 4, pp. 312-319.

Crozes, G. 2001. Practical Aspects of UV Disinfection. AWWARF Report 90875. Project #2623.

Culp, G.L. and R.L. Culp. 1974. New Concepts in Water Purification. Van Norstrand Reinhold Co., New York.

DeMers, L.D. and R.C. Renner. 1993. Alternative Disinfection Technologies for Small Drinking Water Systems. AWWARF Report 90619. Project #621.

Dentel, S.K. et al. 1989. Procedures Manual for Polymer Selection in Water Treatment Plants. AWWARF Report 90553. Project #209.

Dewettinck T., E. Van Houtte, D. Geenens, K. Van Hege, and W. Verstraete. 2001. HACCP (Hazard Analysis and Critical Control Points) to Guarantee Safe Water Reuse and Drinking Water Production--a Case Study. Water Science and Technology. 43(12): 31-8.

DeWolfe, J. et al. Guidance Manual for Coagulant Changeover. AWWARF Report 90958. Project #2512.

Dietrich, A.M. 2004. Practical Taste-and-Odor Methods for Routine Operations: Decision Tree. AWWARF Report 91019. Project #467.

Dietrich, A.M. and R.C. Hoehn. 1991. Taste-and-Odor Problems Associated with Chlorine Dioxide. AWWARF Report 90589. Project #405.

Duranceau, S.J. 2001. Membrane Practices for Water Treatment. AWWA. Denver, CO.

Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Edwards, M. 1997. Predicting DOC Removal During Enhanced Coagulation. Journal of American Water Works Association. 89(5): 78-89.

1   Edwards, M., and S. Reiber. 1997. A General Framework for Corrosion Control Based on
2   Utility Experience. AWWARF Report 90712. Project #910.

3   Edwards, M., and T. Holm. 2001. Role of Phosphate Inhibitors in Mitigating Lead and
4   Copper Corrosion. AWWARF Report 90823 Project #2587.

5   Edwards, M., J.C. Rushing, S. Kvech, and S. Reiber. 2004. Assessing copper pinhole
6   leaks in residential plumbing. Water Science and Technology. 49(2): 83-90.

7   Edwards, M., J.F. Ferguson, S. Reiber. 1994. The Pitting Corrosion of Copper. Journal of
8   American Water Works Association. 86(7): 74-91.

9   Edwards, M., S. Jacobs and D. Dodrill 1999. "Desktop Guidance for Mitigating Pb and
10 Cu Corrosion Byproducts," Journal of the American Water Works Association, 91:5:66-
11 77.

12 Edwards, M., S.H. Reiber. 1997. Predicting Pb and Cu corrosion by-product release using
13 CORRODE software. AWWARF Report 90712.

14 Edwards, M., T.E. Meyer, J. Rehring, J. Ferguson, G. Korshin, and S. Perry. 1996. Role
15 of Inorganic Anions, NOM, and Water Treatment Process in Copper Corrosion.
16 AWWARF Project 90687 Project #831.

17 Effler, S.W. et al. 2005. Origins, Behavior, and a Mechanistic Model for THM Precursors
18 in Lakes and Reservoirs. AWWARF Report 91057F. Project #557.

19 Emmert, G. et al. 2004. Methods for Real-Time Measurement of THMs and HAAs in
20 Distribution Systems. AWWARF Report 91003F. Project #2873.

21 Escobar, I.C. and A.A. Randall. 2001. Case study: Ozonation and distribution system
22 biostability. Journal of American Water Works Association. 93(10): 77-89.

23 Escobar, I.C., A.A. Randall, and J. S. Taylor. 2001. Bacterial Growth in Distribution
24 Systems: Effect of Assimilable Organic Carbon and Biodegradable Dissolved Organic
25 Carbon. Environmental Science and Technology. 35(17): 3442-3447.

26 Faust, S. and O. Aly. 1998. Chemistry of Water Treatment. Second Edition. Lewis
27 Publishers. New York.

28 Finch, G.R., D.W. Smith, and M. Belosevic. 2001. Sequential Disinfection Design
29 Criteria for Inactivation of Cryptosporidium Oocysts in Drinking Water. AWWARF
30 Report 90831. Project #348.

1   Friedman, M. and G. Hamilton. 1997. Enhancing CTs, Coagulation, and Corrosion
2   Control through Carbon Dioxide Injection. Proceedings 1996 Water Quality Technology
3   Conference, Part II. American Water Works Association.

4   Gagnon, G.A., T.S. Dykstra, K.C. O'Leary, R.C. Andrews, C. Chauret and C. Volk.
5   2004. Impact of UV Disinfection on Biological Stability. AWWARF Report 90999F.
6   Project #2723.

7   Galey, C. et al. 2001. Controlling bromate formation. Journal of American Water Works
8   Association. 93(8): 105-115.

9   Gallagher, D.L., R.C. Hoehn, and A.M. Dietrich. 1994. Sources, Occurrence, and Control
10 of Chlorine Dioxide By-Product Residuals in Drinking Water. AWWARF Report 90656.
11 Project #611.

12 Gates, D. 1997. The Chlorine Dioxide Handbook. AWWA. Denver, CO. 177 pp.

13 Gell, R. and J. Bromka. 2003. Successful Application of Chloramines to Manage
14 Disinfection By-Products. New York State Section AWWA. September 2003. Published
15 by O'Brien and Gere.

16 George, D.B. et al. 1990. Case Studies of Modified Disinfection Practices for
17 Trihalomethane Control. AWWARF Report 90574. Project #201.

18 Gianatasio, J.M. 1985. Experience at Tampa, Florida, Using Combined Chlorine to
19 Control THM Production. Paper presented at the North Carolina AWWA/WPLC Joint
20 Technical Conference, November 13, at Charlotte NC.

21 Giani, R., M. Edwards, C. Chung, and J. Wujek. 2004. Lead Profiling Methodologies
22 and Results. Presented at Getting the Lead Out: Analysis & Treatment of Elevated Lead
23 Levels in DC's Drinking Water at the 2004 AWWA WQTC.

24 Global Environment & Technology Foundation. 2000. Final Report: The US EPA
25 Environmental Management System Pilot Program for Local Government.

26 Global Environment & Technology Foundation. 2002. Final Report: Second EMS
27 Initiative for Government Entities (2000-2002).

28 Glucina, K., A. Alvarez, and J.M. Laine. 2000. Assessment of an integrated membrane
29 system for surface water treatment. Proceeding of the conference in drinking and
30 industrial water production. 2: 113-122. Italy, October 2000.

Gollnitz, W.D., J.L.Clancy, J. B. McEwen, and S. C. Garner. 2005. Riverbank Filtration for IESWTR Compliance. 2005. Journal of American Water Works Association. 97(12):64-76.

Gordon, G. 2001. Is all chlorine dioxide created equal? Journal of American Water Works Association. 93(4): 163-174.

Grant, G.B. Sc., CEA, EMS(LA), CEAS. 2004. ISO 14001 and Drinking Water Quality. Environmental Science and Engineering. January, 2004.

Grayman, W.M. et al. 2000. Water Quality Modeling of Distribution System Storage Facilities. AWWARF Report 90774. Projct #260.

Grayman, W.M., R.A. Deininger, and R.M. Males. 2001. Design of Early Warning and Predictive Source-Water Monitoring Systems. AWWARF Report 90878. Project #2527.

Haestad Methods. WaterCAD. Water Distribution Modeling & Management Software.

Harms, L.L. and C. Owen. 2004. Draft. A Guide for the Implementation and Use of Chloramines. AWWARF Report 91018F. Project #2847.

Harrington, G.W., D.R. Noguera, C.C. Bone, A.I. Kandou, P.S. Oldenburg, J.M. Regan, and D. Van Hoven. 2003. Ammonia from Chloramine Decay: Effects on Distribution System Nitrification. AWWARF Report 90949. Project #553.

HDR Engineering, Inc. 2001. Handbook of Public Water Systems. 2nd ed.

Hecht, P.M., and E.A. Turner. 2004. Washington Aqueduct Desktop & Flow-Through Study. Presented at Getting the Lead Out: Analysis & Treatment of Elevated Lead Levels in DC's Drinking Water at the 2004 AWWA WQTC.

Hering, J.G., P.Y. Chen, J.A. Wilkie, M. Elimelech, and S. Liang. 1996. Arsenic removal by ferric chloride. Journal of American Water Works Association. 88(4): 155-167.

Hoehn, R.C. 1993. Chlorine Dioxide Use in Water Treatment: Key Issues Proceedings, 2nd International Symposium, Chlorine Dioxide and Drinking Water Issues. Houston, TX. pp. 1-14.

Hoehn, R.C., A.M. Dietrich, W.S., Farmer, M.P. Orr, R.G. Lee, E.M. Aieta, D.W. Wood III, and G. Gordon. 1990. Household Odors Associated with the Use of Chlorine Dioxide. Journal of American Water Works Association. 82(4):166-172.

Huck, P.M., B.M. Coffey, A. Amirtharajah, and E.J. Bouwer. 2000. Optimizing Filtration in Biological Filters. AWWARF Report 90793. Project #252.

1   Hulsey, R.A. et al. 2004. Evaluation of Ozone and Ultraviolet Light. AWWARF Report
2   91046F. Project #2749.

3   Jacangelo, J.G., C. Gerba, and C.N. Haas. 2002. Inactivation of Waterborne Emerging
4   Pathogens by Selected Disinfectants. AWWARF Report 90886. Project #442. Denver,
5   CO.

6   Jacangelo, J.G., V.P. Olivieri, and K. Kawata. 1987. Mechanism of Inactivation of
7   Microorganisms by Combined Chlorine. AWWA, Denver, CO.

8   Julich, W. and J. Schubert (eds.). Proceedings of International Riverbank Filtration
9   Conference, Nov. 2-4, Duesseldorf. International Arbeitgemeinschaft der Wasserwerke
10   im Rheineinzugsgebiet, Amsterdam.

11   Kawamura, Susumu. 2000. Integrated Design and Operation of Water Treatment
12   Facilities. 2nd ed. John Wiley & Sons, Inc.

13   Kennedy, R.M. and M.E. Richardson. 2004. Ozone and Biofiltration, An Improved Water
14   Quality at Wilmington. PowerPoint Presentation.

15   Khiari, D., S. Barrett, R. Chinn, A. Bruchet, P. Piriou, L. Matia, F. Ventura, I. Suffet, T.
16   Gittelman, and P. Luitweiler. 2002. Distribution Generated Taste-and-Odor Phenomena.
17   AwwaRF Report 90897. Project # 365.

18   Kim, Y., Y. Lee, C.S. Gee, and E. Choi. 1997. Treatment of Taste and Odor Causing
19   Substances in Drinking Water. Water Science and Technology. 35(8): 29-36.

20   Kirmeyer, G. 2002. Guidance Manual for Monitoring Distribution System Water Quality.
21   AWWARF Report 90882. Project #2522.

22   Kirmeyer, G.J. 1990. Lead Control Strategies. AWWARF

23   Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water
24   Quality. AWWARF Report 90798. Project #357.

25   Kirmeyer, G.J. et al. 1995. Nitrification Occurrence and Control in Chloraminated Water
26   Systems. AWWARF Report 90669. Project #710.

27   Kirmeyer, G.J. et al. 2000a. Distribution System Water Quality Changes Following
28   Implementation of Corrosion Control Strategies. AWWARF Report 90764. Project
29   #157.

30   Kirmeyer, G.J. et al. 2004a. Update of Optimizing Chloramine Treatment. AWWARF
31   Report 90993. Project #2760.

Kirmeyer, G.J., A.M. Sandvig, G.L. Pierson, and C.H. Neff. 1994. Development of a Pipe Loop Protocol for Lead Control. AWWARF Report 90650 Project #604

Kirmeyer, G.J., B.M. Murphy, A. Sandvig, G. Korshin, B. Shaha, M. Fabbricino, and G. Burlingame. 2004b. Post Optimization of Lead and Copper Control Monitoring Strategies. AWWARF Report 90996F Project #2679

Klotz, M., P. Werner, and R. Schweisfurth. 1976. Investigations concerning the microbiology of activated carbon filters. Pp. 312-330 in H. Sontheimer, ed. Translation of Reports on Special Problems of Water Technology. Volume 9 Adsorption. Conference held in Karlsruhe, Federal Republic of Germany, 1975. U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio. Report No. EPA 600/9-76-030.

Knappe, D.R.U. et al. 2004. Algae Detection and Removal Strategies for Drinking Water Treatment Plants. AwwaRF Report 90971. Project #360.

Koch, B., S.W. Krasner, M.J. Sclimenti, and W.K. Schimpff. 1991. Predicting the formation of DBPs by the simulated distribution system. Journal of American Water Works Association. 83(10): 62–70.

Kornegay, B.H. 2000c. Natural Organic Matter in Drinking Water: Recommendations to Water Utilities. AWWARF Report 90802. Project #2543.

Korshin, G.V. and J.F. Ferguson. 1999. Corrosion and Metal Release for Lead Containing Materials: Influence of NOM. AWWARF Report 90759 Project #182.

Krasner, S.W. and G. Amy, 1995. Jar-test evaluations of enhanced coagulation. Journal of American Water Works Association. 87(10): 93-107.

Krasner, S.W. et al. 2003. Case Studies of Modified Treatment Practices for Disinfection By-Product Control. AWWARF Report 90946F. Project #369.

Krasner, S.W., and S.E. Barrett. 1985. Aroma and Flavor Characteristics of Free Chlorine and Chloramines. In Proc. Of the Twelfth Annual AWWA Water Quality Technology Conference. AWWA Denver, CO.

Krasner, S.W., K.M. Reagan, J.G. Jacangelo, N.L. Patania, E.M. Aieta, and K.M. Gramith. 1990. Relationships Between Disinfection By-products and Water Quality Parameters: Implications for Formation and Control. In Proc. AWWA Annual Conference. Denver, Colo.: American Water Works Association.

1   Laine, J.M., J.G. Jacangelo, E.W. Cummings, K.E. Carns, J. Mallevialle. 1993. Influence
2   of Bromide on Low Pressure Membrane Filtration for Controlling DBPs in Surface
3   Waters. Journal of American Water Works Association. 85(6).

4   Lange, C. L., T. M. Short, E. Blake. 1994. Development of Zebra Mussel Control
5   Strategies for a Coalition of Vermont Water Suppliers on Lake Champlain. Proceedings
6   of The Fourth International Zebra Mussel Conference, Madison, Wisconsin, March 1994.

7   Lauer, B. 2001. Self-Assessment for Treatment Plant Optimization, International Edition.
8   AWWA Publication. 256 pp.

9   Lauer, William C. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.
10 1,083 pp.

11 LeChevallier, M.W., C.D. Cawthorn, and R.G. Lee. 1988a. Factors Promoting Survival
12 of Bacteria in Chlorinated Water Supplies. Applied and Environmental Microbiology.
13 54(3): 649-654.

14 LeChevallier, M.W., C.D. Cawthorn, and R.G. Lee. 1988b. Inactivation of Biofilm
15 Bacteria. Applied and Environmental Microbiology. 54(10):2492-2499.

16 LeChevallier, M.W., C.D. Lowry, and R.G. Lee. 1990. Disinfection of Biofilms in a
17 Model Distribution System. Journal of American Water Works Association. 82(7): 87-99.

18 LeChevallier, M.W., C.D. Lowry, R.G. Lee, and D.L. Gibbon. 1993. Examining the
19 Relationship Between Iron Corrosion and the Disinfection of Biofilm Bacteria. Journal
20 of the American Water Works Association, 85(7)

21 LeChevallier, M.W., G. Di Giovanni, J.L. Clancy, Z. Bukhari, S. Bukhari, J.S. Rosen, J.
22 Sobrinho, and M.M. Frey. 2002. Source Water Assessment: Variability of Pathogen
23 Concentrations. AwwaRF Report 90906. Project #488.

24 LeChevallier, M.W., N.J. Welch, and D.B. Smith. 1996. Full scale studies of factors
25 related to coliform regrowth in drinking water. Applied and Environmental
26 Microbiology. 62: 2201-2211.

27 LeChevallier, M.W., W.C. Becker, P. Schorr, and R.G. Lee. 1992. Evaluating the
28 Performance of Biologically Active Rapid Sand Filters. Journal of American Water
29 Works Association. 84(4): 136.

30 Leung, K.S., and R.L. Segar. 2000. Adsorption Interactions of S-Triazine Herbicide with
31 Trace Organics in a GAC Filter-Absorber. Presented at the AWWA Conference
32 December, 2000.

Liu, W., H. Wu, Z. Wang, S.L. Ong, J.Y. Hu and W.J. Ng. 2002. Investigation of Assimilable Organic Carbon (AOC) and Bacterial Regrowth in Drinking Water Distribution System. Water Research 36: 891-898.

Logsdon, G.S. et al. 2002. Filter Maintenance and Operations Guidance Manual. AWWARF Report 90908. Project #2511.

Lovins, W.A., III, S.J. Duranceau, R.M. Gonzalez, and J.S. Taylor. 2003. Optimized Coagulation Assessment for a Highly Organic Surface Water Supply. Journal of American Water Works Association. 95(10): 94-108.

Lowther, E.D. and R.H. Mosher. 1984. Detecting and Eliminating Coliform Regrowth. Proceedings of the AWWA Water Quality Technology Conference, Denver, CO. AWWA. Denver, CO.

Lytle, D.A. & Schock, M.R., 2005. The Formation of Pb(IV) Oxides in Chlorinated Water. Journal of the American Water Works Association, 97:11:102.

Maas, R.P., J.C. Pitch, and A.M. Smith. 2005. Effects of Fluorides and Chloramines on Lead Leaching from Leaded-Brass Surfaces. Asheville Environmental Quality Institute Technical Report #04-137

Mackey, E.D., J. Malley, Jr., R.S. Cushing, M. Janex-Habibi, N. Picard, and J. Laine, 2001. Bridging Pilot-Scale Testing to Full-Scale Design of UV Disinfection Systems. AWWARF Report 90991. Project #2593.

Mallevialle, J. et al. 1996. Water Treatment Membrane Processes. AWWARF Report 90716. Project #826.

Malley, J.P. et al. 2001. Full Scale Implimention of UV in Groundwater Disinfection Systems. AWWARF Report 90860. Project #474.

Malley, J.P. Jr. et al. 2004. Inactivation of Pathogens with Innovative UV Technologies. AWWARF Report 91024. Project #2593.

Marshall, B., J. Rushing, and M. Edwards. 2003. Confirming the role of aluminum solids and chlorine in copper pitting corrosion. In Proceedings of AWWA Annual Conference. Denver CO.

Martel, Kathy, Gregory Kirmeyer, Amie Hanson, Melita Stevens, Joanne Mullenger, and Daniel Deere. 2006. Application of HACCP for Distribution System Protection. AWWARF Report 91131. Project #2856. Denver, CO.

Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO. 900 pp.

McGuire, M., et al. 2004. Water Utility Self-Assessment for the Management of Aesthetic Issues. AWWARF Report 90978F. Project #2777.

McGuire, M.J., J.L. McLain, and A. Obolensky. 2002. Information Collection Rule Data Analysis. AWWARF Report 90947. Project #2799.

McGuire, M.J., M.S. Pearthree, N.K. Blute, K.F. Arnold, and T. Hoogerwerf. 2006. Nitrification Control by Chlorite Ion at Pilot Scale. Journal of the American Water Works Association, 98(1):95-105

McGuire, M.J., N.I. Lieu, and M.S. Pearthree. 1999. Using chlorite ion to control nitrification. Journal of American Water Works Association. 91(10): 52-61.

McMeen. 2001. Alternate Filtration: Placing New Technology in an Old Regulatory Box. American Water Works Association, Membrane Conference Proceedings.

McTigue, N. and D. Cornwell. 1994. The Hazardous Potential of Activated Carbons Used in Water Treatment. AWWARF Report 90640. Project #620.

Means, E.G., K.N. Scott, M.L. Lee, and R.W. Wolfe. 1986. Effects of Chlorine and Ammonia Application Points on Bactericidal Efficiency. Journal of American Water Works Association. 78(1): 62-69.

Mitch, W.A., and D.L. Sedlak. 2002. Factors Controlling Nitrosoamine Formation During Wastewater Chlorination. Water Supply. 2(3): 191-198.

Mofidi, A.A. et al. 2001. Disinfection of Cryptosporidium parvum with polychromatic UV light. Journal of American Water Works Association. 93(6): 95-109.

Montgomery Watson Inc. 1998. Palm Beach County Water Utilities Department Water Treatment Plant No. 3 Membrane Softening Facility Operations Manual Final Report. Pages 4-19 to 4-20.

Mullenger, J., G. Ryan, and J. Hearn. 2002. A Water Authority's Experience with HACCP. Water Supply. 2(5-6): 149-155.

Mysore, C. et al. 2003. Impact of Water Quality on the Inactivation of Bacterial and Viral Pathogens. AwwaRF Report 90972F. Project #2592.

Najm, I. 2000. Case Studies of the Impacts of Treatment Changes on Biostability in Full-Scale Distribution Systems. AWWARF Report 90816. Project #361.

Najm, I. and R. Rhodes Trussell. 2001. NDMA formation in water and wastewater. Journal of American Water Works Association. 93(2): 92-99.

1   Najm, I., M. Kennedy, and W. Naylor. 2005. Lignite versus Bituminous GAC for
2   Biofiltration - A Case Study. Journal of American Water Works Association. 97(1): 94-
3   101.

4   National Research Council. 2000. Identifying Future Drinking Water Contaminants.
5   National Academy Press. Washington, D.C.

6   Nero, W. et al. 2001. Public Involvement . . . Making It Work. AWWARF Report 90865.
7   Project #2526.

8   NSF International. 1996. NSF International Environmental Management System
9   Demonstration Project - Final Report.

10 NWRI and AWWARF. 2000. Ultraviolet Disinfection Guidelines for Drinking Water and
11 Water Reuse. AWWARF Report. Project #2674.

12 Ollos, P.J., P.M. Huck, R.M. Slawson. 2003. Factors Affecting Biofilm Accumulation in
13 Model Distribution Systems. Journal of American Water Works Association. 94(1).

14 Olstein, M.A. 2001. Best Practices for a Continually Improving Customer Responsive
15 Organization. AWWARF Report 90868. Project #2525.

16 Owen, D.M. 1998. Removal of DBP Precursors by GAC Adsorption. AWWARF Report
17 90744. Project #816.

18 Panayides, N. 1999. Operational Procedures of a New 27 MGD Nanofiltration Membrane
19 Water Treatment Plant (WTP No. 9) in South Florida. Palm Beach County Water
20 Utilities Department.

21 Pennsylvania's Multi State Working Group Pilot. The Effects of ISO 14001
22 Environmental Management Systems on the Environmental and Economic Performance
23 of Organizations. March 27, 1999.

24 Powell, J. et al. 2004. Predictive Models for Water Quality in Distribution Systems.
25 AWWARF Report 91023F. Project #2865.

26 Prévost, M.(editor) et al. 2005. Biodegradable Organic Matter in Drinking Water
27 Treatment and Distribution. AWWA.

28 Price, M.L. et al. 1994. Ozone and Biological Treatment for DBP Control and Biological
29 Stability. AWWARF Report 90649. Project #504.

30 Randtke, S.J., and R.C. Hoehn. 1999. Removal of DBP precursors by Enhanced
31 Coagulation and Lime Softening. AWWARF Report 90783. Project #814.

1   Randtke, S.J., C.E. Thiel, M.Y. Liao, and C.N. Yamaya. 1982. Removing Soluble
2   Organic Contaminants by Lime-Softening. Journal of American Water Works
3   Association. 74(4): 192.

4   Raucher, R. et al. 2005. The Value of Water: Concepts, Estimates, and Applications for
5   Water Managers. AwwaRF Report 91068F. Project #2855.

6   Ray, C. (ed.). 2001. Riverbank Filtration: Understanding Contaminant Biogeochemistry
7   and Pathogen Removal.NATO Science Series IV. Earth and Environmental Sciences -
8   Vol. 14. Kluwer Academic Publishers.

9   Reckhow, D.A. 1999. Control of Disinfection Byproduct Formation Using Ozone. In
10 Singer, P.C. (Ed) Formation and Control of Disinfection By-Products in Drinking Water.
11 pp. 179-204 AWWA, Denver, CO.

12 Reckhow, D.A. and P.C. Singer. 1985. Mechanisms of Organic Halide Formation During
13 Fulvic Acid Chlorination and Implications with Respect to Pre-ozonation. Water
14 Chlorination: Environmental Impact and Health Effects. 5: 1229-1257 (Lewis Publishers,
15 Inc., Chelsea, MI, 1985).

16 Reckhow, D.A. J.K. Edzwald, and J.E. Tobiason. 1993. Ozone as an Aid to Coagulation
17 and Filtration. AWWARF Report 90643. Project #403.

18 Redaud, J.L. 2005. ISO/TC 224 "Service Activities Relating to Drinking Water Supply
19 Systems and Wastewater Systems - Quality Criteria of the Service and Performance
20 Indicators". ISO. March 31, 2005.

21 Reiber, S. 1991. Corrosion Effects by Chloramines. AWWARF Denver, CO.

22 Reiber, S. 1993. Chloramine Effects on Distribution System Materials. AWWARF
23 Report 90624. Project #508.

24 Renner, R. 2004. Plumbing the Depths of D.C.'s Drinking Water Crisis. Environmental
25 Science and Technology. 38(12): 224-227.

26 Renner, R.C. and B.A. Hegg. 1997. Self-Assessment Guide for Surface Water Treatment
27 Plant Optimization. AWWARF Report 90736. Project #274.

28 Rettie, M. et al. 2005. Effective Practices to Select, Acquire, and Implement a Utility
29 CIS. AWWARF Report 91071. Project # 3007.

30 Roig, R. and A. Saponara. 2003. ISO 14001 Environmental Management Systems: A
31 Complete Implementation Guide. ISO.

1   Routt, J.C. 2004. Lowering DBPs in Combined Systems. Opflow. 30(4): 1-7.

2   Routt, J.C. and N.G. Pizzi 2000. Kentucky-American Water's Cooperative, Step-wise
3   Process of Assisting Two Small Contiguous Systems in Complying with Pending D/DBP
4   Requirements. Proceedings of AWWA Water Quality Technology Conference.

5   Rushing, J.C., and M. Edwards. 2002. Effect of aluminum solids and chlorine on cold
6   water pitting of copper. Proceedings of AWWA Water Quality Technology Conference.

7   Sarin, P., et al. 2003. Iron Release from Corroded, Unlined Cast-Iron Pipes. Journal of
8   American Water Works Association. 95(11): 85-96.

9   Sarin, P., V.L. Snoeyink, J. Bebee, K.K. Jim, M.A. Beckett, W.M. Kriven, J.A. Clement.
10   2004. Iron Release from Corroded Iron Pipes in Drinking Water Distribution Systems:
11   Effect of Dissolved Oxygen. Water Research. 38: 1259-1269.

12   Schippers, J.C. et al. 2004. Integrated Membrane Systems. AWWARF Report 90899.
13   Project #264.

14   Schock, M.R., Wagner, I. & Oliphant, R., 1996 (Second ed.) The Corrosion and
15   Solubility of Lead in Drinking Water. Internal Corrosion of Water Distribution Systems,
16   pp. 131-230. AWWA Research Foundation/TZW, Denver, CO.

17   Schock, Michael. 1996. Corrosion Inhibitor Applications in Drinking Water Treatment:
18   Conforming to the Lead and Copper Rule. Presented at NACE Corrosion 1996
19   Conference.

20   Schock, M.R., 2001. Tetravalent Lead: A Hitherto Unrecognized Control of Tap Water
21   Lead Contamination. In Proc. of the AWWA Water Quality Technology Conference.
22   Denver, Colo.: AWWA.

23   Schock, M.R. & Giani, R., 2004. Oxidant/Disinfectant Chemistry and Impacts on Lead
24   Corrosion. In Proc. Of the AWWA Water Quality Technology Conference.

25   Schock, M.R., Scheckel, K.G., DeSantis, M., and Gerke, T.L., 2005. Mode of
26   Occurrence, Treatment and Monitoring Significance of Tetravalent Lead, In Proc. Of the
27   AWWA Water Quality Technology Conference.

28   Scott, K.N., J.F. Green, H.D. Do, and S.J. McLean. 1995. Arsenic Removal by
29   Enhanced Coagulation. Journal of the American Water Works Association 87(4)

30   Shaw, J.P., J.P. Malley Jr., and S. Willoughby. 2000. Effects of UV irradiation on organic
31   matter. Journal of American Water Works Association. 92(4): 157-167.

1   Shorney, H.L., and S.J. Randtke. 1994. Enhanced Lime Softening for the Removal of
2   Disinfection By-Product Precursors. In Proceedings of the 1994 Annual AWWA
3   Conference. Denver CO.

4   Singer, P.C. (Ed.). 1999. Formation and Control of Disinfection By-Products in Drinking
5   Water. AWWA. Denver, CO. 424 pp.

6   Singer, P.C. 1992. Formation and Characterization of Disinfection Byproducts. Presented
7   at the First International Conference on the Safety of Water Disinfection: Balancing
8   Chemical and Microbial Risks.

9   Singer, P.C. and S.D. Chang. 1989. Correlations between trihalomethanes and total
10   organic halides formed during water treatment. Journal of American Water Works
11   Association. 81(8): 61-65.

12   Singer, P.C. et al. 2002. Relative Dominance of HAAs and THMs in Treated Drinking
13   Water. AWWARF Report 90844. Project #339.

14   Skadsen, J. 1993. Nitrification in a Distribution System. Journal of American Water
15   Works Association. 85(7): 95-103.

16   Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA.
17   Denver, CO. 85 pp.

18   Snyder, J.K., and AK. Deb. 2002. Impacts of Fireflow on Distribution System Water
19   Quality, Design, and Operation. AWWARF Report 90913. Project #2554.

20   Sorg, T.J. 1988. Methods for Removing Uranium from Drinking Water. Journal of the
21   American Water Works Association, 80(7)

22   Speitel, G.E. Jr. and J.M. Symons.1998. Advanced Oxidation/Biodegradation Processes
23   for the Destruction of TOC and Disinfection By-Product Precursors. AWWARF Report
24   #90758. Project #289.

25   Speitel, G.E. Jr. et al. 2004. Disinfection By-Product Formation and Control During
26   Chloramination. AWWARF Report 91040F. Project #2677.

27   States, S., R. Tomko, M. Scheuring, and L. Casson. 2002. Enhanced coagulation and
28   removal of Cryptosporidium. Journal of American Water Works Association. 94(11): 67-
29   77.

30   Stevens, A.A., C.J. Slocum, D.R. Seeger, and G.G. Robeck. 1976. Chlorination of
31   Organics in Drinking Water. Journal of American Water Works Association. 68(11):615.

1   Stevens, A.A., L.A. Moore. and R.J. Miltner. 1989. Formation and Control of Non-
2   Trihalomethane Byproducts. Journal of American Water Works Association. 81(8): 54.

3   Stevenson, B. 1997. Controlling Zebra Mussels at Water Treatment Plant Intakes.
4   AWWARF Report 90612. Project #614.

5   Stevenson, B. 1999. Controlling Zebra Mussels at Water Treatment Plant Intakes Part II.
6   AWWARF Report. Project #821.

7   Stolarik, G., and J.D. Christie. 1997. A Decade of Ozonation in Los Angeles. Conference
8   proceedings, IOA Pan American Group Annual Conference, Lake Tahoe, NV.

9   Summers, R.S., S.M. Hooper, H.M. Shukairy, G. Solarik, and D. Owen. 1996. Assessing
10   DBP yield: uniform formation conditions. Journal of American Water Works
11   Association. 88(6): 80–93.

12   Symons, J.M. et al. 1998. Factors Affecting DBP Formation During Chloramination.
13   AWWARF Report 90728. Project #803.

14   Tatham, C., E. Tatham, and J. Mobley. 2004. Customer Attitudes, Behavior and the
15   Impact of Communications Efforts. AWWARF Report 90975. Project #2613.

16   Taylor, J.S. et al. 2005. Effects of Blending on Distribution System Water Quality.
17   AWWARF Report 91065F. Project #2702.

18   Texas Natural Resource Conservation Commission (TNRCC). 2005. Texas Optimization
19   Program (TOP). http://www.tceq.state.tx.us/permitting/water_supply/pdw/swmor/top/

20   Thompson, P.L., and W.L. Paulson 1998. Dewaterability of Alum and Ferric Coagulation
21   Sludges. Journal of American Water Works Association. 90(4): 164-170.

22   Tikkanen, M. et al. 2001. Guidance Manual for Disposal of Chlorinated Water.
23   AWWARF Report 90863. Project #2513.

24   Tokuno, S. 1999. Granulated Activated Carbon Filtration and Chloramine. Water
25   Engineering Management, 146(1):16-21

26   U.S. Bureau of Reclamation and I. Moch & Associates. 2003. WTCost©. Development
27   of program sponsored by the American Membrane Technology Association.

28   U.S. Bureau of Reclamation. 1998. The Desalting and Water Treatment Membrane
29   Manual: A Guide to Membranes for Municipal Water Treatment (2nd Edition). Technical
30   Service Center, Water Treatment Engineering and Research, Denver, CO.

U.S. EPA 2002c. Lead and Copper Monitoring and Reporting Guidance for Public Water Systems. Office of Water. EPA 816-R-02-009.

U.S. EPA. 1989. National Primary Drinking Water Regulations; Giardia lamblia, Viruses, and Legionella, Maximum Contaminant Levels, and Turbidity, and Heterotrophic Bacteria. (Surface Water Treatment Rule), Final Rule. 43 FR 27486. June 29, 1989.

U.S. EPA. 1991. Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources. Developed by Malcolm Pirnie and HDR. USEPA, Washington, DC. 568 pp.

U.S. EPA. 1992. Control of Biofilm Growth in Drinking Water Distribution Systems. Office of Research and Development, EPA 625/R-92/001.

U.S. EPA. 1994. National Primary Drinking Water Regulations: Disinfection and Disinfection Byproducts; Proposed Rule. 59 FR 38668. July 29, 1994.

U.S. EPA. 1998a. Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program. EPA 625/6-91/027.

U.S. EPA. 1998b. National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment Rule; Final Rule. 63 FR 69477. December 16, 1998 http://www.epa.gov/safewater/mdbp/ieswtrfr.html

U.S. EPA. 1998c. National Primary Drinking Water Regulations: Disinfectants and Disinfection By Products; Final Rule. 63 FR 69389. December 16, 1998. http://www.epa.gov/safewater/mdbp/dbpfr.html

U.S. EPA. 1999a. Disinfection Profiling and Benchmarking Guidance Manual. EPA 815-R-99-013.

U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.

U.S. EPA. 1999c. Uncovered Finished Water Reservoirs Guidance Manual. EPA 815-R-99-011.

U.S. EPA. 1999d. Guidance Manual for Compliance with the Interim Enhanced Surface Water Treatment Rule: Turbidity Provisions. EPA 815-R-99-010.

U.S. EPA. 1999e. Unfiltered Systems Guidance Manual.

U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.

1   U.S. EPA. 1999g. Guidance Manual for Conducting Sanitary Surveys of Public Water
2   Systems; Surface Water and Ground Water Under the Direct Influence (GWUDI). EPA
3   815-R-99-016.

4   U.S. EPA. 1999h. Enhanced Coagulation and Enhanced Precipitative Softening Guidance
5   Manual. EPA 815-R-99-012.

6   U.S. EPA. 1999i. Lead and Copper Rule Minor Revision Fact Sheet. EPA 815-F-99-010.

7   U.S. EPA. 2000a. National Primary Drinking Water Regulations: Radionuclides Rule;
8   Final Rule. 65 FR 76707. December 7, 2000.
9   http://www.epa.gov/safewater/rads/radfr.html

10   U.S. EPA. 2000b. National Primary Drinking Water Regulations for Lead and Copper. 65
11   FR 1949. January 12, 2000. http://www.epa.gov/fedrgstr/EPA-
12   WATER/2000/January/Day-12/w3.htm

13   U.S. EPA. 2000c. Lead and Copper Rule: Summary of Revisions. Office of Water. EPA
14   815-R-99-020.

15   U.S. EPA. 2001a. Implementation Guidance for the Stage 1 Disinfectants/Disinfection
16   Byproducts Rule. Office of Water. EPA 816-R-01-012.

17   U.S. EPA. 2001b. State Implementation Guidance for the Lead and Copper Rule Minor
18   Revisions. Office of Water. EPA 816-R-01-021.

19   U.S. EPA. 2001c. Controlling Disinfection By-Products and Microbial Contaminants in
20   Drinking Water. Office of Research and Development. EPA/600/R-01/110.

21   U.S. EPA. 2001d. National Primary Drinking Water Regulations: Filter Backwash
22   Recycling Rule; Final Rule. 66 FR 31085. June 8, 2001.
23   http://www.epa.gov/safewater/mdbp/fr-fbr.html

24   U.S. EPA. 2001e. National Primary Drinking Water Regulations: Arsenic and
25   Clarifications to Compliance and New Source Contaminants Monitoring . 66 FR 6975.
26   January 22, 2001. http://www.epa.gov/fedrgstr/EPA-WATER/2001/January/Day-
27   22/w1668.htm

28   U.S. EPA. 2001f. Total Coliform Rule: A Quick Reference Guide. EPA 816-F-01-035.
29   November, 2001. http://www.epa.gov/safewater/tcr/pdf/qrg_tcr_v10.pdf

30   U.S. EPA. 2001g. A Small System Guide to the Total Coliform Rule. Office of Water.
31   EPA 816-R-01-017A. http://www.epa.gov/safewater/smallsys/small-tcr.pdf

1   U.S. EPA. 2001h. Water Treatment Plant Model (Version 2.0).

2   U.S. EPA. 2001i. The Surface Water Analytical Tool (Version 1.1). March 20, 2001.

3   U.S. EPA. 2001j. 1999 Drinking Water Infrastructure Needs Survey: Modeling the Cost
4   of Infrastructure. Office of Water. EPA 816-R-01-005.

5   U.S. EPA. 2001k. Stage 1 Disinfectants and Disinfection Byproducts Rule: A Quick
6   Reference Guide. Office of Water. EPA 816-F-01-010. May, 2001.
7   http://www.epa.gov/safewater/mdbp/qrg_st1.pdf

8   U.S. EPA. 2001l. Interim Enhanced Surface Water Treatment Rule: A Quick Reference
9   Guide. Office of Water. EPA 816-F-01-011. May, 2001.
10   http://www.epa.gov/safewater/mdbp/qrg_ieswtr.pdf

11   U.S. EPA. 2001m. Filter Backwash Recycling Rule: A Quick Reference Guide. Office of
12   Water. EPA 816-F-01-019. June 2001. http://www.epa.gov/safewater/mdbp/fbrr_qrg.pdf

13   U.S. EPA. 2001n. Arsenic and Clarifications to Compliance and New Source Monitoring
14   Rule: A Quick Reference Guide. Office of Water. EPA 816-F-01-004. January, 2001.
15   http://www.epa.gov/safewater/arsenic/pdfs/quickguide.pdf

16   U.S. EPA. 2002a. National Primary Drinking Water Regulations: Long Term 1 Enhanced
17   Surface Water Treatment Rule. 67 FR 1811. January 14, 2002.
18   http://www.epa.gov/fedrgstr/EPA-WATER/2002/January/Day-14/w409.htm

19   U.S. EPA. 2002b. EPANET 2.0. http://www.epa.gov/ORD/NRMRL/wswrd/epanet.html

20   U.S. EPA. 2002c. Long Term 1 Enhanced Surface Water Treatment Rule: A Quick
21   Reference Guide. Office of Water. EPA 816-F-02-001. January, 2002.
22   http://www.epa.gov/safewater/mdbp/lt1eswtr-quick-ref.pdf

23   U.S. EPA. 2003a. Draft LT2ESWTR Toolbox Guidance Manual. Office of Water. EPA
24   815-D-03-009. June, 2003.

25   U.S. EPA. 2003b. Draft Ultraviolet Disinfection Guidance Manual. Office of Water. EPA
26   815-D-03-007. June, 2003.

27   U.S. EPA. 2003c. Draft Significant Excursion Guidance Manual. Office of Water. EPA
28   815-D-03-004. July, 2003.

29   U.S. EPA. 2003d. Revised Guidance Manual for Selecting Lead and Copper Control
30   Strategies. Office of Water. EPA 816-R-03-001. March, 2003.

1   U.S. EPA. 2004a. Draft Filter Surveillance Manual (June 2004).

2   U.S. EPA. 2004b. Draft Coagulation Control Manual (July 2004).

3   U.S. EPA. 2004c. Draft Process Monitoring Manual (July 2004).

4   U.S. EPA. 2004d. National Primary Drinking Water Regulations; Minor Corrections and
5   Clarification to Drinking Water Regulations; National Primary Drinking Water
6   Regulations for Lead and Copper. 69 FR 38850. June 29, 2004.
7   http://www.epa.gov/fedrgstr/EPA-WATER/2004/June/Day-29/w14604.htm

8   U.S. EPA. 2004e. Guidance Manual for Compliance with the Long Term 1 Enhanced
9   Surface Water Treatment Rule: Turbidity Provisions. EPA 816-F-02-001.

10   U.S. EPA. 2004f. The Long Term 1 Enhanced Surface Water Treatment Rule
11   Implementation Guidance. EPA 816-R-04-008.

12   U.S. EPA. 2004g. Lead and Copper Rule: A Quick Reference Guide. Office of Water.
13   EPA 816-F-04-009. March, 2004.

14   U.S. EPA. 2005a. Occurrence Assessment for the Final Stage 2 Disinfectants and
15   Disinfection Byproducts Rule. EPA 815-R-05-011. December, 2005.

16   U.S. EPA. 2005b. Membrane Filtration Guidance Manual. Office of Water. EPA 815-R-
17   06-009. November, 2005.

18   U.S. EPA. 2005c. A Regulator's Guide to the Management of Radioactive Residuals
19   from Drinking Water Treatment Technologies. USEPA 816-R-05-004.

20   U.S. EPA. 2005d. Technologies and Costs for the Final Long Term 2 Enhanced Surface
21   Water Treatment Rule and Final Stage 2 Disinfectants and Disinfection Byproducts Rule.
22   EPA 815-R-05-012. December, 2005.

23   U.S. EPA. 2005e. Occurrence and Exposure Assessment for the Long Term 2 Enhanced
24   Surface Water Treatment Rule. EPA-821-R-06-002.

25   U.S. EPA. 2006a. Initial Distribution System Evaluation Guidance Manual for the Final
26   Stage 2 DBPR. Office of Water. EPA 815-B-06-002.

27   U.S. EPA. 2006b. Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2
28   DBPR) Implementation Guidance. Office of Water. EPA 816-R-06-002. June, 2006.

29   U.S. EPA. 2006c. Draft Long Term 2 Enhanced Surface Water Treatment Rule
30   (LT2ESWTR) Implementation Guidance. EPA 816-R-06-006. June, 2006.

1 U.S. EPA. 2006d. Source Water Monitoring Guidance Manual for Public Water Systems
2 for the Long Term 2 Enhanced Surface Water Treatment Rule. Office of Water. EPA
3 815-R-06-005. February, 2006.

4 Uchida, M. and A. Okuwaki. 1999. Dissolution Behavior of Lead Plates in Aqueous
5 Nitrate Solutions. Corrosion Science. 41:1977

6 Urfer, D. et al. 1999. Modeling enhanced coagulation to improve ozone disinfection.
7 Journal of American Water Works Association. 91(3): 59-73.

8 Urfer, D., P.M. Huck, S.D.J. Booth, and B.M. Coffey. 1997. Biological Filtration for
9 BOM and Particle Removal: A Critical Review. Journal of American Water Works
10 Association. 89(12):83-98.

11 Valentine, R.L. 1998. Chloramine Decomposition in Distribution System and Model
12 Waters. AWWARF Report 90721. Project #937.

13 Van der Kooij, D. 1997. Bacterial Nutrients and Biofilm Formation Potential within
14 Drinking Water Distribution Systems. Conference Proceedings, AWWA Water Quality
15 Technology Conference.

16 Veazey, M.V. 2004. New Research May Explain Pinholes in Copper Tubing. Materials
17 Performance. 43(5): 18-22

18 Volk, C.J. and M.W. LeChevallier. 2002. Effects of Conventional Treatment on AOC
19 and BDOC Levels. Journal of American Water Works Association. 94(6):112-123.

20 Volk, C.J., R. Hofmann, C. Chauret, G.A. Gagnon, G. Ranger, and R.C. Andrews. 2002.
21 Implementation of chlorine dioxide disinfection: Effects of the treatment change on
22 drinking water quality in a full-scale distribution system. Journal of Environmental
23 Engineering and Science. 1: 323-330.

24 Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition.
25 AWWA. Denver, CO. 278 pp.

26 Wang, J., S. Hubbs, and R. Song. 2002. Evaluation of Riverbank Filtration as a Drinking
27 Water Treatment Process. AWWARF Report 90922. Project #2622.

28 Wesner, G.M. Copyright 1994-2000. W/W Costs, Windows Version 3.0.

29 Westerhoff, G.P., et al. 1998a. The Changing Water Utility: Creative Approaches to
30 Effectiveness and Efficiency. AWWA.

Westerhoff, G.P., et al. 1998b. NOM's role in bromine and bromate formation during ozonation. Journal of American Water Works Association. 90(2): 82-94.

White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.

Wilczak, A. L. Hoover, and H.H. Lai. 2003. Effects of Treatment Changes on Chloramine Demand and Decay. Journal of the American Water Works Association. 95(7):94-107

Wilczak, A., J.G. Jacangelo, J.P. Marcinko, L.H. Odell, G.J. Kirmeyer, and R.L. Wolfe. 1996. Occurrence of Nitrification in Chloraminated Distribution Systems. Journal of American Water Works Association. 88(7): 74-85.

Williams, M.D., B.M. Coffey, and S.W. Krasner, 2003. Evaluation of pH and Ammonia for Controlling Bromate During Cryptosporidium Disinfection. Journal of American Water Works Association. 95(10): 82-93.

Wolfe, R.L. 1990. Ammonia-Oxidizing Bacteria in a Chloraminated Distribution System: Seasonal Occurrence, Distribution, and Disinfection Resistance. Applied and Environmental Microbiology. 56: 541.

Wolfe. R.L., E.G. Means, M.K. Davis, and S.E. Barrett. 1988. Biological Nitrification in Covered Reservoirs Containing Chloraminated Water. Journal of American Water Works Association. 80(9): 109-114.

World Health Organization. 2004a. Guidelines for Drinking Water Quality, 3rd Edition. Geneva, Switzerland. World Health Organization.

World Health Organization. 2004b. Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking Water. Edited by M.W. LeChevallier and K.K. Au. ISBN: 1 84339 069 8. Published by IWA Publishing, London, UK.

Wubbena, R.L. 2002a. Strategic Business Planning as a Water Resource Management Tool. AWWARF Report 90905. Project # 2698.

Xie, Y., et al. 2004. Haloacetic Acid Removal Using Granular Activated Carbon. AWWARF Report 91041F. Project #2825.

Zhou, P. and J. Neemann. 2005. Use of Chlorine Dioxide and Ozone for Control of Disinfection By-Products. AWWARF Report 90981F. Project #2742.

1   This page intentionally left blank.

Index

Appendix A
Summary of Pertinent Drinking Water Regulations

This page intentionally left blank.

Appendix A
Summary of Pertinent Drinking Water Regulations

This appendix contains quick reference guides for the major rules discussed in this guidance manual. The quick reference guides are brief summaries of the major requirements of the rules. More detailed information on rule requirements and guidance can be found on EPA's Web site at *http://www.epa.gov/safewater*. The following is a list of quick reference guides that are included in this appendix and the order in which they appear:

Rule	*Date of Promulgation*	*Contaminant of Concern*	*Rule Summary Information Available from EPA*
Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)	December 2005	Microbial Pathogens	Fact Sheet
Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR)	December 2005	Disinfectants and Disinfection Byproducts	Fact Sheet
Arsenic and Clarifications to Compliance and New Source Monitoring Rule	January 2001	Arsenic	Quick Reference Guide
Lead and Copper Rule (LCR)	June 1991	Lead and Copper	Quick Reference Guide
LCR Clarification of Requirements for Collecting Samples and Calculating Compliance	March 2004	Lead and Copper	Fact Sheet
Total Coliform Rule (TCR)	June 1989	Microbial Pathogens	Quick Reference Guide
Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 D/DBPR)	December 1998	Disinfectants and Disinfection Byproducts	Quick Reference Guide
Interim Enhanced Surface Water Treatment Rule (IESWTR)	December 1998	Microbial Pathogens	Quick Reference Guide
Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR)	January 2002	Microbial Pathogens	Quick Reference Guide
Filter Backwash Recycling Rule (FBRR)	June 2001	Filter Backwash (Microbial Pathogens)	Quick Reference Guide

Fact Sheet - Long Term 2 Enhanced Surface Water Treatment Rule

In the past 30 years, the Safe Drinking Water Act (SDWA) has been highly effective in protecting public health and has also evolved to respond to new and emerging threats to safe drinking water. Disinfection of drinking water is one of the major public health advances in the 20th century. One hundred years ago, typhoid and cholera epidemics were common through American cities; disinfection was a major factor in reducing these epidemics.

In the past 15 years, we have learned that there are specific microbial pathogens, such as *Cryptosporidium*, which can cause illness, and are highly resistant to traditional disinfection practices. We also know that the disinfectants themselves can react with naturally-occurring materials in the water to form byproducts, which may pose health risks.

Amendments to the SDWA in 1996 require EPA to develop rules to balance the risks between microbial pathogens and disinfection byproducts (DBPs). The Stage 1 Disinfectants and Disinfection Byproducts Rule and Interim Enhanced Surface Water Treatment Rule, promulgated in December 1998, were the first phase in a rulemaking strategy required by Congress as part of the 1996 Amendments to the Safe Drinking Water Act.

The Long Term 2 Enhanced Surface Water Treatment Rule builds upon earlier rules to address higher risk public water systems for protection measures beyond those required for existing regulations.

The Long Term 2 Enhanced Surface Water Treatment Rule and the Stage 2 Disinfection Byproduct Rule are the second phase of rules required by Congress. These rules strengthen protection against microbial contaminants, especially *Cryptosporidium*, and at the same time, reduce potential health risks of DBPs.

Questions and Answers

What is the LT2ESWTR?

The purpose of Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) is to reduce illness linked with the contaminant *Cryptosporidium* and other pathogenic microorganisms in drinking water. The LT2ESWTR will supplement existing regulations by targeting additional *Cryptosporidium* treatment requirements to higher risk systems. This rule also contains provisions to reduce risks from uncovered finished water reservoirs and provisions to ensure that systems maintain microbial protection when they take steps to decrease the formation of disinfection byproducts that result from chemical water treatment.

Current regulations require filtered water systems to reduce source water *Cryptosporidium* levels by 2-log (99 percent). Recent data on *Cryptosporidium* infectivity and occurrence indicate that this treatment requirement is sufficient for most systems, but additional treatment is necessary for certain

higher risk systems. These higher risk systems include filtered water systems with high levels of *Cryptosporidium* in their water sources and all unfiltered water systems, which do not treat for *Cryptosporidium*.

The LT2ESWTR is being promulgated simultaneously with the Stage 2 Disinfection Byproduct Rule to address concerns about risk tradeoffs between pathogens and DBPs.

What are the health risks of Cryptosporidium?

Cryptosporidium is a significant concern in drinking water because it contaminates most surface waters used as drinking water sources, it is resistant to chlorine and other disinfectants, and it has caused waterborne disease outbreaks. Consuming water with *Cryptosporidium* can cause gastrointestinal illness, which may be severe and sometimes fatal for people with weakened immune systems (which may include infants, the elderly, and people who have AIDS).

Who must comply with this rule?

This regulation will apply to all public water systems that use surface water or ground water under the direct influence of surface water.

What does the rule require?

Monitoring*:* Under the LT2ESWTR, systems will monitor their water sources to determine treatment requirements. This monitoring includes an initial two years of monthly sampling for *Cryptosporidium*. To reduce monitoring costs, small filtered water systems will first monitor for *E. coli*—a bacterium which is less expensive to analyze than *Cryptosporidium*—and will monitor for *Cryptosporidium* only if their *E. coli* results exceed specified concentration levels.

Monitoring starting dates are staggered by system size, with smaller systems beginning monitoring after larger systems. Systems must conduct a second round of monitoring six years after completing the initial round to determine if source water conditions have changed significantly. Systems may use (grandfather) previously collected data in lieu of conducting new monitoring, and systems are not required to monitor if they provide the maximum level of treatment required under the rule.

Cryptosporidium* treatment:* Filtered water systems will be classified in one of four treatment categories (bins) based on their monitoring results. The majority of systems will be classified in the lowest treatment bin, which carries no additional treatment requirements. Systems classified in higher treatment bins must provide 90 to 99.7 percent (1.0 to 2.5-log) additional treatment for *Cryptosporidium*. Systems will select from a wide range of treatment and management strategies in the "microbial toolbox" to meet their additional treatment requirements. All unfiltered water systems must provide at least 99 or 99.9 percent (2 or 3-log) inactivation of *Cryptosporidium*, depending on the results of their monitoring. These *Cryptosporidium* treatment requirements reflect consensus recommendations of the Stage 2 Microbial and Disinfection Byproducts Federal Advisory Committee.

Other requirements: Systems that store treated water in open reservoirs must either cover the reservoir or treat the reservoir discharge to inactivate 4-log virus, 3-log *Giardia lamblia*, and 2-log *Cryptosporidium*. These requirements are necessary to protect against the contamination of water that occurs in open reservoirs. In addition, systems must review their current level of microbial treatment before making a significant change in their disinfection practice. This review will assist systems in maintaining protection against microbial pathogens as they take steps to reduce the formation of disinfection byproducts under the Stage 2 Disinfection Byproducts Rule, which EPA is finalizing along with the LT2ESWTR.

What are the benefits of the rule?

The LT2ESWTR will improve the control of *Cryptosporidium* and other microbiological pathogens in drinking water water systems with the highest risk levels. EPA estimates that full compliance with the LT2ESWTR will reduce the incidence of cryptosporidiosis - the gastrointestinal illness caused by ingestion of *Cryptosporidium* - by 89,000 to 1,459,000 cases per year, with an associated reduction of 20 to 314 premature deaths. The monetized benefits associated with these reductions ranges from $253 million to $1.445 billion per year. The additional *Cryptosporidium* treatment requirements of the LT2ESWTR will also reduce exposure to other microbial pathogens, such as *Giardia*, that co-occur with *Cryptosporidium*. Additional protection from microbial pathogens will come from provisions in this rule for reviewing disinfection practices and for covering or treating uncovered finished water reservoirs, though EPA has not quantified these benefits.

What are the costs of the rule?

The LT2ESWTR will result in increased costs to public water systems and states. The average annualized present value costs of the LT2ESWTR are estimated to range from $92 to $133 million (using a three percent discount rate). Public water systems will bear approximately 99 percent of this total cost, with states incurring the remaining 1 percent. The average annual household cost is estimated to be $1.67 to $2.59 per year, with 96 to 98 percent of households experiencing annual costs of less than $12 per year.

What technical information will be available on the rule?

The following guidance documents will be available:
- Source Water Monitoring Guidance
- Microbial Laboratory Guidance
- Small Entity Compliance Guidance
- Microbial Toolbox Guidance Manual
- Ultraviolet Disinfection Guidance Manual
- Membrane Filtration Guidance Manual
- Simultaneous Compliance Guidance Manual
- Low-pressure Membrane Filtration for Pathogen Removal: Application, Implementation, and Regulatory Issues

Where can I find more information about this notice and the LT2ESWTR?

For general information on the LT2ESWTR, contact the Safe Drinking Water Hotline at (800) 426-4791. The Safe Drinking Water Hotline is open Monday through Friday, excluding legal holidays, from 10:00 a.m. to 4:00 p.m., Eastern time. For copies of the Federal Register notice of the regulation or technical fact sheets, visit the EPA Safewater website at http://www.epa.gov/safewater/disinfection/lt2. For technical inquiries, email stage2mdbp@epa.gov.

Fact Sheet: Stage 2 Disinfectants and Disinfection Byproducts Rule

In the past 30 years, the Safe Drinking Water Act (SDWA) has been highly effective in protecting public health and has also evolved to respond to new and emerging threats to safe drinking water. Disinfection of drinking water is one of the major public health advances in the 20th century. One hundred years ago, typhoid and cholera epidemics were common through American cities; disinfection was a major factor in reducing these epidemics.

However, the disinfectants themselves can react with naturally-occurring materials in the water to form byproducts, which may pose health risks. In addition, in the past 10 years, we have learned that there are specific microbial pathogens, such as *Cryptosporidium*, which can cause illness, and are highly resistant to traditional disinfection practices.

Amendments to the SDWA in 1996 require EPA to develop rules to balance the risks between microbial pathogens and disinfection byproducts (DBPs). The Stage 1 Disinfectants and Disinfection Byproducts Rule and Interim Enhanced Surface Water Treatment Rule, promulgated in December 1998, were the first phase in a rulemaking strategy required by Congress as part of the 1996 Amendments to the Safe Drinking Water Act.

The Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR) builds upon the Stage 1 DBPR to address higher risk public water systems for protection measures beyond those required for existing regulations.

The Stage 2 DBPR and the Long Term 2 Enhanced Surface Water Treatment Rule are the second phase of rules required by Congress. These rules strengthen protection against microbial contaminants, especially *Cryptosporidium*, and at the same time, reduce potential health risks of DBPs.

Questions and Answers

What is the Stage 2 DBPR?

The Stage 2 Disinfection Byproducts Rule will reduce potential cancer and reproductive and developmental health risks from disinfection byproducts (DBPs) in drinking water, which form when disinfectants are used to control microbial pathogens. Over 260 million individuals are exposed to DBPs.

This final rule strengthens public health protection for customers by tightening compliance monitoring requirements for two groups of DBPs, trihalomethanes (TTHM) and haloacetic acids (HAA5). The rule targets systems with the greatest risk and builds incrementally on existing rules. This regulation will reduce DBP exposure and related potential health risks and provide more equitable public health protection.

The Stage 2 DBPR is being promulgated simultaneously with the Long Term 2 Enhanced Surface Water Treatment Rule to address concerns about risk tradeoffs between pathogens and DBPs.

What does the rule require?

Under the Stage 2 DBPR, systems will conduct an evaluation of their distribution systems, known as an Initial Distribution System Evaluation (IDSE), to identify the locations with high disinfection byproduct concentrations. These locations will then be used by the systems as the sampling sites for Stage 2 DBPR compliance monitoring.

Compliance with the maximum contaminant levels for two groups of disinfection byproducts (TTHM and HAA5) will be calculated for each monitoring location in the distribution system. This approach, referred to as the locational running annual average (LRAA), differs from current requirements, which determine compliance by calculating the running annual average of samples from all monitoring locations across the system.

The Stage 2 DBPR also requires each system to determine if they have exceeded an operational evaluation level, which is identified using their compliance monitoring results. The operational evaluation level provides an early warning of possible future MCL violations, which allows the system to take proactive steps to remain in compliance. A system that exceeds an operational evaluation level is required to review their operational practices and submit a report to their state that identifies actions that may be taken to mitigate future high DBP levels, particularly those that may jeopardize their compliance with the DBP MCLs.

Who must comply with the rule?

Entities potentially regulated by the Stage 2 DBPR are community and nontransient noncommunity water systems that produce and/or deliver water that is treated with a primary or residual disinfectant other than ultraviolet light.

A community water system (CWS) is a public water system that serves year-round residents of a community, subdivision, or mobile home park that has at least 15 service connections or an average of at least 25 residents.

A nontransient noncommunity water system (NTNCWS) is a water system that serves at least 25 of the same people more than six months of the year, but not as primary residence, such as schools, businesses, and day care facilities.

What are disinfection byproducts (DBPs)?

Disinfectants are an essential element of drinking water treatment because of the barrier they provide against waterborne disease-causing microorganisms. Disinfection byproducts (DBPs) form when disinfectants used to treat drinking water react with naturally occurring materials in the water (e.g., decomposing plant material).

Total trihalomethanes (TTHM - chloroform, bromoform, bromodichloromethane, and dibromochloromethane) and haloacetic acids (HAA5 - monochloro-, dichloro-, trichloro-, monobromo-, dibromo-) are widely occurring classes of DBPs formed during disinfection with chlorine and chloramine. The amount of trihalomethanes and haloacetic acids in drinking water can change from day to day, depending on the season, water temperature, amount of disinfectant added, the amount of plant material in the water, and a variety of other factors.

Are THMs and HAAs the only disinfection byproducts?

No. The four THMs (TTHM) and five HAAs (HAA5) measured and regulated in the Stage 2 DBPR act as indicators for DBP occurrence. There are many other known DBPs, in addition to the possibility of unidentified DBPs present in disinfected water. THMs and HAAs typically occur at higher levels than other known and unknown DBPs. The presence of TTHM and HAA5 is representative of the occurrence of many other chlorination DBPs; thus, a reduction in the TTHM and HAA5 generally indicates a reduction of DBPs from chlorination.

What are the costs and benefits of the rule?

Quantified benefits estimates for the Stage 2 DBPR are based on reductions in fatal and non-fatal bladder cancer cases. EPA has projected that the rule will prevent approximately 280 bladder cancer cases per year. Of these cases, 26% are estimated to be fatal. Based on bladder cancer alone, the rule is estimated to provide annualized monetized benefit of $763 million to $1.5 billion.

The rule applies to approximately 75,000 systems; a small subset of these (about 4%) will be required to make treatment changes. The mean cost of the rule is $79 million annually. Annual household cost increases in the subset of plants adding treatment are estimated at an average of $5.53, with 95 percent paying less than $22.40.

What are the compliance deadlines?

Compliance deadlines are based on the sizes of the public water systems (PWSs). Wholesale and consecutive systems of any size must comply with the requirements of the Stage 2 DBPR on the same schedule as required for the largest system in the combined distribution system (defined as the interconnected distribution system consisting of wholesale systems and consecutive systems that receive finished water). Compliance activities are outlined in the following table.

PUBLIC WATER SYSTEMS	ACTIONS			
	Submit IDSE monitoring plan, system specific study plan, or 40/30 certification	Complete an initial distribution system evaluation (IDSE)	Submit IDSE Report	Begin subpart V (Stage 2) compliance monitoring
CWSs and NTNCWSs serving at least 100,000	October 1, 2006	September 30, 2008	January 1, 2009	April 1, 2012
CWSs and NTNCWSs serving 50,000 - 99,999	April 1, 2007	March 31, 2009	July 1, 2009	October 1, 2012
CWSs and NTNCWSs serving 10,000 - 49,999	October 1, 2007	September 30, 2009	January 1, 2010	October 1, 2013
CWSs serving fewer than 10,000	April 1, 2008	March 31, 2010	July 1, 2010	October 1, 2013
NTNCWSs serving fewer than 10,000	NA	NA	NA	October 1, 2013

*States may grant up to an additional two years for systems making capital improvements.

What technical information will be available on the rule?

The following Guidance Documents will be available:
- Initial Distribution System Evaluation (IDSE) Guidance Manual
- Operational Evaluation Guidance Manual
- Consecutive Systems Guidance Manual
- Small Systems (SBREFA) Guidance Manual
- Simultaneous Compliance Guidance Manual

Where can I find more information about this notice and the Stage 2 DBPR?

For general information on the rule, please visit the EPA Safewater website at http://www.epa.gov/safewater/disinfection/stage2 or contact the Safe Drinking Water Hotline at 1-800-426-4791. The Safe Drinking Water Hotline is open Monday through Friday, excluding legal holidays, from 10:00 a.m. to 4:00 p.m., Eastern Time. For technical inquiries, email stage2mdbp@epa.gov.

EPA

Arsenic and Clarifications to Compliance and New Source Monitoring Rule: A Quick Reference Guide

Overview of the Rule

Title	**Arsenic and Clarifications to Compliance and New Source Monitoring Rule 66 FR 6976 (January 22, 2001)**
Purpose	**To improve public health by reducing exposure to arsenic in drinking water.**
General Description	**Changes the arsenic MCL from 50 µg/L to 10 µg/L; Sets arsenic MCLG at 0; Requires monitoring for new systems and new drinking water sources; Clarifies the procedures for determining compliance with the MCLs for IOCs, SOCs, and VOCs.**
Utilities Covered	**All community water systems (CWSs) and nontransient, noncommunity water systems (NTNCWSs) must comply with the arsenic requirements. EPA estimates that 3,024 CWSs and 1,080 NTNCWSs will have to install treatment to comply with the revised MCL.**

Public Health Benefits

Implementation of the Arsenic Rule will result in . . .	• **Avoidance of 16 to 26 non-fatal bladder and lung cancers per year.** • **Avoidance of 21 to 30 fatal bladder and lung cancers per year.** • **Reduction in the frequency of non-carcinogenic diseases.**

Critical Deadlines & Requirements

Consumer Confidence Report Requirements *

Report Due	*Report Requirements*
July 1, 2001	**For the report covering calendar year 2000, systems that detect arsenic between 25 µg/L and 50 µg/L must include an educational statement in the consumer confidence reports (CCRs).**
July 1, 2002 and beyond	**For reports covering calendar years 2001 and beyond, systems that detect arsenic between 5 µg/L and 10 µg/L must include an educational statement in the CCRs.**
July 1, 2002 - July 1, 2006	**For reports covering calendar years 2001 to 2005, systems that detect arsenic between 10 µg/L and 50 µg/L must include a health effects statement in their CCRs.**
July 1, 2007 and beyond	**For reports covering calendar year 2006 and beyond, systems that are in violation of the arsenic MLC (10 µg/L) must include a health effects statement in their CCRs.**

For Drinking Water Systems

Jan. 22, 2004	**All *NEW* systems/sources must collect initial monitoring samples for all IOCs, SOCs, and VOCs within a period and frequency determined by the State.**
Jan. 1, 2005	**When allowed by the State, systems may grandfather data collected after this date.**
Jan. 23, 2006	**The new arsenic MCL of 10 µg/L becomes effective. All systems must begin monitoring or when allowed by the State, submit data that meets grandfathering requirements.**
Dec. 31, 2006	**Surface water systems must complete initial monitoring or have a State approved waiver.**
Dec. 31, 2007	**Ground water systems must complete initial monitoring or have a State approved waiver.**

For States

Spring 2001	**EPA meets and works with States to explain new rules and requirements and to initiate adoption and implementation activities.**
Jan. 22, 2003	**State primacy revision applications due.**
Jan. 22, 2005	**State primacy revision applications due from States that received 2-year extensions.**

* For required educational and health effects statements, please see 40 CFR 141.154.
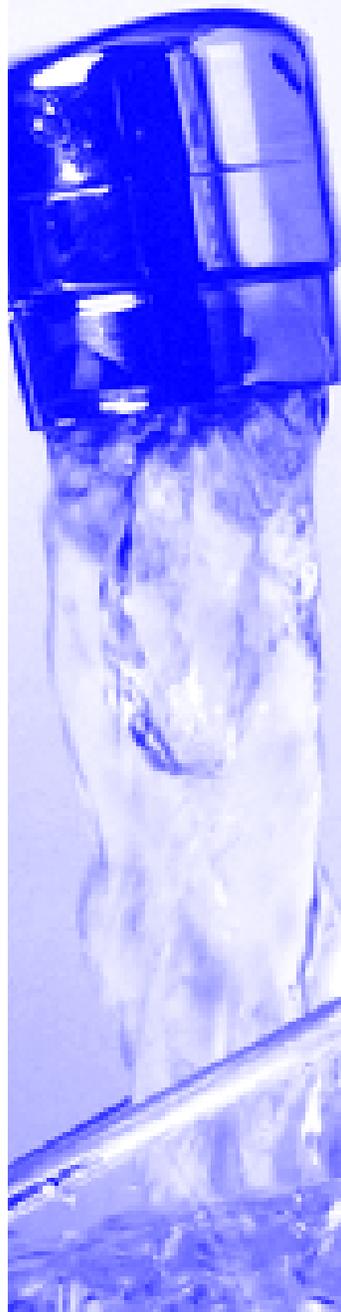
Compliance Determination (IOCs, VOCs, and SOCs)

1. Calculate compliance based on a running annual average at each sampling point.

2. Systems will not be in violation until 1 year of quarterly samples have been collected (unless fewer samples would cause the running annual average to be exceeded.)

3. If a system does not collect all required samples, compliance will be based on the running annual average of the samples collected.

Monitoring Requirements for Total Arsenic [1]

Initial Monitoring

One sample after the effective date of the MCL (January 23, 2006). Surface water systems must take annual samples. Ground water systems must take one sample between 2005 and 2007.

Reduced Monitoring

| If the initial monitoring result for arsenic is less than the MCL . . . | Ground water systems must collect one sample every 3 years. Surface water systems must collect annual samples. |

Increased Monitoring

A system with a sampling point result above the MCL must collect quarterly samples at that sampling point, until the system is reliably and consistently below the MCL.

[1] All samples must be collected at each entry point to the distribution system, unless otherwise specified by the State.

For additional information on the Arsenic Rule

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA Web site at www.epa.gov/safewater; or contact your State drinking water representative. EPA will provide arsenic training over the next year.

Applicability of the Standardized Monitoring Framework to Arsenic

FIRST COMPLIANCE CYCLE

3rd Compliance Period
1999   2000   2001

SECOND COMPLIANCE CYCLE

1st Compliance Period
2002   2003   2004

2nd Compliance Period
2005   2006   2007

3rd Compliance Period
2008   2009   2010

Below Trigger Level

GROUND WATER

No Waiver

Waiver*

SURFACE WATER

No Waiver

Waiver*

Final Rule
Jan. 23, 2001

Effective Date of Revised MCL
Jan. 23, 2006

Surface Water Systems:
Initial Samples Collected by
Dec. 31, 2006

Ground Water Systems:
Initial Samples Collected by
Dec. 31, 2007

Key
■ One sampling event.

*Waivers are not permitted under the current arsenic requirements. States may issue 9 year monitoring waivers under the revised final arsenic rule. To be eligible for a waiver, surface water systems must have monitored annually for at least 3 years. Ground water systems must conduct a minimum of 3 rounds of monitoring with detection limits below 10 μg/L.

EPA
United States
Environmental Protection
Agency

Lead and Copper Rule: A Quick Reference Guide

Overview of the Rule

Title	**Lead and Copper Rule (LCR)[1], 56 FR 26460 - 26564, June 7, 1991**
Purpose	**Protect public health by minimizing lead (Pb) and copper (Cu) levels in drinking water, primarily by reducing water corrosivity. Pb and Cu enter drinking water mainly from corrosion of Pb and Cu containing plumbing materials.**
General Description	**Establishes action level (AL) of 0.015 mg/L for Pb and 1.3 mg/L for Cu based on 90th percentile level of tap water samples. An AL exceedance is not a violation but can trigger other requirements that include water quality parameter (WQP) monitoring, corrosion control treatment (CCT), source water monitoring/treatment, public education, and lead service line replacement (LSLR).**
Utilities Covered	**All community water systems (CWSs) and non-transient, non-community water systems (NTNCWSs) are subject to the LCR requirements.**

Public Health Benefits

Implementation of the LCR has resulted in . . .	▸ **Reduction in risk of exposure to Pb that can cause damage to brain, red blood cells, and kidneys, especially for young children and pregnant women.** ▸ **Reduction in risk of exposure to Cu that can cause stomach and intestinal distress, liver or kidney damage, and complications of Wilson's disease in genetically predisposed people.**

Lead and Copper Tap Sampling Requirements

▸ **First draw samples must be collected by all CWSs & NTNCWSs at cold water taps in homes/buildings that are at high risk of Pb/Cu contamination as identified in 40 CFR 141.86(a).**
▸ **Number of sample sites is based on system size (see Table 1).**
▸ **Systems must conduct monitoring every 6 months unless they qualify for reduced monitoring (see Table 2).**

Table 1: Pb and Cu Tap and WQP Tap Monitoring

Size Category	System Size	Number of Pb/Cu Tap Sample Sites		Number of WQP Tap Sampling Sites	
		Standard	**Reduced**	**Standard**	**Reduced**
Large	**> 100K**	100	50	25	10
	50,001-100K	60	30	10	7
Medium	**10,001 - 50K**	60	30	10	7
	3,301 - 10K	40	20	3	3
Small	**501 - 3,300**	20	10	2	2
	101 - 500	10	5	1	1
	≤ 100	5	5	1	1

Table 2: Criteria for Reduced Pb/Cu Tap Monitoring[a]

Can Monitor . . .	If the System . . .
Annually	1. Serves ≤ 50,000 and is ≤ both ALs for 2 consecutive 6-month monitoring periods; *or* 2. Meets Optimal Water Quality Parameter (OWQP) specifications for 2 consecutive 6-month monitoring periods.
Triennially	1. Serves ≤ 50,000 and is ≤ both ALs for 3 consecutive years of monitoring; *or* 2. Meets OWQP specifications for 3 consecutive years of monitoring; *or* 3. Has 90th percentile Pb levels ≤ 0.005 mg/L & 90th percentile Cu level ≤ 0.65 mg/L for 2 consecutive 6-month periods (*i.e*, accelerated reduced Pb/Cu tap monitoring), *or* 4. Meets the 40 CFR 141.81(b)(3) criteria.
Once every 9 years	Serves ≤ 3,300 and meets monitoring waiver criteria found at 40 CFR 141.86(g).

[a] Samples are collected at reduced number of sites (see Table 1 above).

Treatment Technique and Sampling Requirements

CORROSION CONTROL TREATMENT INSTALLATION: All large systems (except systems that meet the requirements of 40 CFR 141.81(b)(2) or (3)) must install CCT. Medium and small systems that exceed either AL must install CCT.

WATER QUALITY PARAMETER MONITORING: All large systems are required to do WQP monitoring. Medium and small systems that exceed either AL are required to do WQP monitoring.

Treatment Technique and Sampling Requirements if the AL is Exceeded

❶ Water Quality Parameter (WQP) Monitoring

▸ All systems serving > 50,000 people, and those systems serving ≤ 50,000 people if 90th percentile tap level > either AL, must take WQP samples during the same monitoring periods as Pb/Cu tap sample.

▸ Used to determine water corrosivity, and if needed, to help identify type of CCT to be installed and how CCT should be operated (*i.e.*, establishes OWQP levels).

▸ WQPs include: pH, alkalinity, calcium, conductivity (initial WQP monitoring only), orthophosphate (if phosphate-based inhibitor is used); silica (if silicate-based inhibitor is used), and temperature (initial WQP monitoring only).

▸ Samples are collected within distribution system (*i.e.*, WQP tap samples), with number of sites based on system size (see Table 1), and at each entry point to distribution system (EPTDS).

▸ Systems installing CCT, must conduct follow-up monitoring for 2 consecutive 6-month periods – WQP tap monitoring is conducted semi-annually; EPTDS monitoring increases to every two weeks.

▸ After follow-up monitoring, State sets ranges of values for the OWQPs.

▸ Reduced WQP tap monitoring is available for systems in compliance with OWQPs; *Reduced monitoring does not apply to EPTDS monitoring.*

▸ For systems ≤ 50,000, WQP monitoring is not required whenever 90th percentile tap levels are ≤ both ALs.

❷ Public Education (PE)

▸ Only required if Pb AL is exceeded *(no public education is required if only Cu AL exceeded).*

▸ Informs Public Water System's (PWS) customers about health effects, sources, and what can be done to reduce exposure.

▸ Includes billing inserts sent directly to customers, pamphlets or brochures distributed to hospitals & other locations that provide services to pregnant woman & children, and for some CWSs, newspaper notices and public service announcements (PSAs) submitted to TV/radio stations.

▸ System must begin delivering materials within 60 days of Pb AL exceedance and continue every 6 months for PSAs and annually for all other forms of delivery for as long as it exceeds Pb AL.

▸ Different delivery methods and mandatory language for CWSs & NTNCWSs.

▸ Can discontinue delivery whenever ≤ Pb AL; but must recommence if Pb AL subsequently exceeded.

▸ PE requirements are in addition to the Public Notification required in 40 CFR Subpart Q.

❸ Source Water Monitoring and Treatment

▸ All systems that exceed Pb or Cu AL must collect source water samples to determine contribution from source water to total tap water Pb/Cu levels and make a source water treatment (SOWT) recommendation within 6 months of the exceedance.

▸ One set of samples at each EPTDS is due within 6 months of first AL exceedance.

▸ If State requires SOWT; system has 24 months to install SOWT.

▸ After follow-up Pb/Cu tap and EPTDS monitoring, State sets maximum permissible levels for Pb & Cu in source.

❹ Corrosion Control Treatment

▸ Required for all large systems (except systems that meet the requirements of 40 CFR 141.81(b)(2) or (b)(3)) and medium/small systems that exceed either AL. The system shall recommend optimal CCT within 6 months.

▸ Corrosion control study required for large systems.

▸ If State requires study for medium or small systems, it must be completed within 18 months.

▸ Once State determines type of CCT to be installed, PWS has 24 months to install CCT.

▸ Systems installing CCT must conduct 2 consecutive 6-months of follow-up monitoring.

▸ After follow-up Pb/Cu tap & WQP monitoring, State sets OWQPs.

▸ Small & medium systems can stop CCT steps if ≤ both ALs for 2 consecutive 6-month monitoring periods.

If the system continues to exceed the AL after installing CCT and/or SOWT...

❺ Lead Service Line (LSL) Monitoring

▸ Two types of sampling associated with LSL replacement (LSLR):

- *Optional* - Monitoring from LSL to determine need to replace line. If all Pb samples from line ≤ 0.015 mg/L then LSL does not need to be replaced and counts as replaced line.

- *Required* - Monitoring if entire LSL is **not** replaced to determine impact from "partial" LSLR. Sample is collected that is representative of water in service line that is partially replaced.

▸ Monitoring only applies to system subject to LSLR.

❻ Lead Service Line Replacement

▸ System must replace LSLs that contribute more than 0.015 mg/L to tap water levels.

▸ Must replace 7% of LSL per year; State can require accelerated schedule.

▸ If only a portion of a LSL is replaced, PWS must:

- Notify customers at least 45 days prior to replacement about the potential for increased Pb levels;
- Collect sample within 72 hours of replacement and mail/post results within 3 days of receipt of results.

▸ Systems can discontinue LSLR whenever ≤ Pb AL in tap water for 2 consecutive monitoring periods.

For additional information on the LCR, call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA web site at www.epa.gov/safewater/lcrmr/implement.html; or contact your State drinking water representative.

NOV 23 2004

MEMORANDUM

SUBJECT: Lead and Copper Rule - Clarification of Requirements for Collecting Samples and Calculating Compliance

FROM: Benjamin H. Grumbles
Acting Assistant Administrator

TO: Regional Administrators
Water Division Directors
Regions I-X

This memo reiterates and clarifies elements of the Lead and Copper Rule (LCR) associated with the collection and management of lead and copper samples and the calculation of the lead 90th percentile for compliance. Over the past several months, Headquarters has been conducting a national review of implementation of the LCR. This review consists of both data analysis and feedback from expert panels on aspects of the rule. Headquarters is continuing its review, and will be making a determination in early 2005 on specific areas of the rule that may require changes in regulation or need clarification through guidance or training.

One area identified for additional guidance is the management of lead and copper samples and the calculation of the lead 90th percentile. Because the need for additional guidance was identified in both Headquarters' data review and the expert panels, Headquarters is addressing this area prior to the final determination on rule and guidance changes. This guidance reflects the requirements of the LCR as it is currently written. These issues may be revisited if EPA makes a determination that changes should be made to the LCR.

1)   What samples are used to calculate the 90th percentile?

We have received several questions regarding what tap samples should be used to calculate the 90th percentile for lead, specifically, where utilities collect samples beyond the minimum number required by the regulations. EPA regulations require water systems to develop a targeted sampling pool, focused on those sites with the greatest risk of lead leaching. All compliance samples used to determine the 90th percentile must come from that sampling pool. All sample results from a system's sampling pool during the monitoring period must be included

in the 90th percentile calculation, even if this includes more samples than the required minimum number needed for compliance. [40 CFR 141.86(e)] For example, consider a situation where a system sends out sample kits to 150 households to ensure that it will have a sufficient number of samples to meet its required 100 samples for compliance. If the system receives sample results from 140 households, it would use the results of the 140 samples in calculating the 90th percentile.

In some cases, a utility may choose to take a confirmation sample to verify a high or low concentration. It is entirely possible for the concentration of a confirmation sample to be significantly higher or lower than the concentration of the original sample. However, where confirmation samples are taken, the results of the original and confirmation sample must be used in calculating the 90th percentile. The LCR does not allow substitution of results with "confirmation" samples, nor does it allow the averaging of initial and confirmation samples as a single sampling result. While we support re-sampling at a home with high lead levels, all sample results from the sampling pool collected within the monitoring period must be included in the calculation.

> **Inclusion of samples in**
> **90th Percentile Calculations**
>
> **40 CFR 141.86(e)** "The results of any additional monitoring conducted in addition to the minimum requirements of this section shall be considered by the system and the state in making any determinations (i.e.; calculating the 90th percentile lead or copper level) under this subpart."
>
> **40 CFR 141.80(c)(3)(i)** "The results of all lead and copper samples taken during a monitoring period shall be placed in ascending order from the sample with the lowest concentration to the sample with the highest concentration. ..." [emphasis added]

2) What should utilities do with sample results from customer-requested sampling programs?

EPA regulations require water systems to develop a targeted sampling pool, focused on those sites with the greatest risk of lead leaching. All compliance samples used to determine the 90th percentile must come from that sampling pool. [40 CFR 141.80(c)(1)] ("Samples collected at sites not meeting the targeting criteria may not be used in calculating the 90th percentile lead and copper levels." 56 Fed Reg. 26518 (June 7, 1991)). Maintaining a consistent set of compliance sample sites provides the system with a baseline against which to measure the 90th percentile over time. If a system designates sites which were not sampled during previous monitoring periods, it must notify the state and include an explanation of why the sampling sites have changed. [40 CFR 141.90(a)(1)(v) and 141.90(h)(2)]

In addition to compliance sampling, many water systems have additional programs to test for lead in drinking water at the request of homeowners. Customer-requested samples that are not collected as part of the system's regular compliance sampling pool may or may not meet the sample site selection criteria, and the system may not have sufficient information to determine whether they do or not. Including results from samples that do not meet the criteria could

inappropriately reduce the 90th percentile value. Therefore, samples collected under these programs should not be used to calculate the 90th percentile, except in cases where the system is reasonably able to determine that the site selection criteria for compliance sampling are satisfied.

However, even though these customer-requested samples are not used for the 90th percentile calculation, the sample results must still be provided to the state. [40 CFR 141.90(g)] If a significant number of customer-requested samples are above the lead action level, the state should re-evaluate the corrosion control used by the system and the composition of the compliance sampling pool. Further, where any results are above the action level, we strongly urge systems to follow up with the affected customers to provide them with information on ways to reduce their risk of exposure to elevated lead levels in drinking water.

3) What should states do with samples taken outside of the sampling compliance period?

The regulations require that systems on reduced monitoring collect samples during the period between June and September, unless the state has approved an alternate period. [40 CFR 141.86(d)(4)(iv)] Only those samples collected during the compliance monitoring period may be included in the 90th percentile calculation. [40 CFR 141.80(c)(3)]

An exception to this is where a state invalidates a sample and the system must collect a replacement sample in order to have a sufficient number with which to calculate compliance. The system must collect its replacement sample within 20 days of the invalidation. Even if the date of collection occurs after the closure of the monitoring period (but within 20 days of the invalidation), the results must be included in the 90th percentile calculation. [40 CFR 141.86(f)(4)]

Although samples collected outside the sampling compliance period should not be used in the compliance calculation, they must still be provided to the state [40 CFR 141.90(g)], as is the case with customer-requested samples.

4) What should states do to calculate compliance if the minimum number of samples are not collected?

As noted in guidance released earlier this year[1], states must calculate the 90th percentile even if the minimum number of samples are not collected. The LCR states that the 90th percentile level is calculated based on "all samples taken during a monitoring period" and does not require that the minimum required number of samples must be collected in order to calculate the 90th percentile level. [40 CFR 141.80(c)]

---

[1] See March 9, 2004 memorandum from Cynthia Dougherty to Jane Downing at http://www.epa.gov/safewater/lcrmr/pdfs/memo_lcmr_lead_compliance_calculation.pdf

A system which fails to collect the minimum required number of samples incurs a monitoring and reporting violation and is thus required to conduct Tier 3 Public Notification (PN) [40 CFR 141.204(a)] and report the violation in its Consumer Confidence Report (CCR) [40 CFR 141.153(f)(1)]. The system will return to compliance for the monitoring and reporting violation when it completes these tasks and has completed appropriate monitoring and reporting for two consecutive 6-month monitoring periods (or one round of monitoring for a system on reduced monitoring). [*State Implementation Guidance for the LCRMR*, EPA-816-R-01-021]

5)   What is a proper sample?

We have received numerous requests to clarify the LCR with respect to proper samples and grounds for invalidation.

Calculating the 90th Percentile

40 CFR §141.80(c)(3) – "The 90th percentile lead and copper levels shall be computed as follows:
(i) The results of all lead and copper samples taken during a monitoring period shall be placed in ascending order from the sample with the lowest concentration to the sample with the highest concentration. Each sampling result shall be assigned a number, ascending by single integers beginning with the number 1 for the sample with the lowest contaminant level. The number assigned to the sample with the highest contaminant level shall be equal to the total number of samples taken.
(ii) The number of samples taken during the monitoring period shall be multiplied by 0.9.
(iii) The contaminant concentration in the numbered sample yielded by the calculation in paragraph (c)(3)(ii) is the 90th percentile contaminant level.
(iv) For water systems serving less than 100 people that collect 5 samples per monitoring period, the 90th percentile is computed by taking the average of the highest and second highest concentrations.

The LCR was designed to ensure that samples are collected from locations which have the highest risk of elevated lead concentrations. The rule established a tiering system (Attachment A) that would guide utilities in selecting locations for tap sampling that are considered high risk and requires that the sampling pool be comprised of Tier 1 sites, if they are available. [40 CFR 141.86(a)]

The LCR also defines a proper sample as a first draw sample, 1 liter in volume, that is taken after water has been standing in plumbing for at least six hours, and from an interior tap typically used for consumption – cold water kitchen or bathroom sink tap in residences. [40 CFR 141.86(b)(2)] There is no outer limit on standing time.

To ensure that sampling is conducted properly, the LCR requires that samples be collected by the system or by residents if they have been properly instructed by the water system. As added insurance that the system gives proper instructions, the rule does not allow water systems to challenge sample results based on alleged homeowner errors in sample collection. [40 CFR 141.86(b)(2)]

6) How can utilities avoid problems with sample collection?

In order to avoid any problems with sample collection, the utility may wish to do the sampling itself or review the sample collection information before sending it to the lab. If the utility chooses to use residents to perform the sampling, it should provide clear instructions and a thorough chain-of-custody form for residents to fill out when the sample is taken. This will allow the laboratory or utility to eliminate improperly collected samples prior to the actual analysis. For example, if a sample bottle is only half full, then it should not be analyzed by the laboratory. Likewise, if the documentation accompanying the sample indicates that it was taken from an outside tap, the sample should not be analyzed. Systems may need to make arrangements to collect replacement samples for samples that are not analyzed by the laboratory.

Once a sample is analyzed, the results may not be challenged by the water system. As explained by Question #1 of this memorandum, the results for all samples from the compliance sampling pool must be included in the 90th percentile calculation unless there are grounds for invalidation. Improper sampling by residents is not a grounds for invalidation under 40 CFR 141.86(f).

7) On what grounds may a sample be invalidated?

The regulations allow the state to invalidate a lead or copper tap sample only if it can document that at least one of the following conditions has occurred:
1. The laboratory establishes that improper sample analysis caused erroneous results;
2. The state determines that the sample was taken from a site that did not meet the site selection criteria of this section;
3. The sample container was damaged in transit; or
4. There is substantial reason to believe that the sample was subject to tampering. [40 CFR 141.86(f)(1)]

We interpret the second condition to mean a site that is not part of the compliance sampling pool, that has not been identified as a Tier 1 or other high risk site, or that has been altered in such a way that it no longer meets the criteria of a high-risk site (e.g., new plumbing or the addition of a water softener).

It is important to note that states may not invalidate a sample solely on the grounds that a follow-up sample result is higher or lower than that of the original sample. [40 CFR 141.86(f)(3)] The system must report the results of all the samples to the state, and provide supporting documentation for all samples it believes should be invalidated. [40 CFR 141.86(f)(2)] The state must provide its formal decision on whether or not to invalidate the sample(s) in writing. If a state makes a determination to invalidate the sample, the decision and the rationale for the decision must be provided in writing. [40 CFR 141.86(f)(3)]

In conducting the national implementation review, we have noticed that some utilities

may have requested invalidation of samples because they believe that there was improper sampling on the part of the homeowner (e.g., drawing water from the incorrect tap). This is a concern because there may be a tendency to only consider sampling errors when there are high results, even though there could be sampling errors that would lead to artificially low results (e.g., collecting a sample after the line was flushed). In any event, EPA takes a strict interpretation of the invalidation requirements in the LCR. If a system allows residents to perform sampling as part of the targeted sampling pool, the system may not challenge the accuracy of sampling results because it believes there were errors in sample collection. [40 CFR 141.86(b)(2)] The state may only invalidate samples based on the criteria described above.

In sum, if a water system (1) sends a sample bottle to a home within its compliance sampling pool, (2) receives the sample back from the homeowner, (3) sends the sample to the laboratory for analysis, and (4) receives results from the analysis back from the lab; that result must be used in calculating the 90th percentile. The only exception to this is if the state invalidates the result in accordance with the regulation.

Conclusion

The Agency is continuing its wide-ranging review of implementation of the LCR and will use the information to determine what changes should be made to existing guidance, training and/or the regulatory requirements. This memo should help to provide clarification on issues related to calculating the 90th percentile and proper management of tap samples as required under the LCR. Please work with your states to ensure that they understand the requirements so that they may work with the public water systems under their jurisdiction to address any misinterpretations of the regulations. If you have additional questions or concerns, please contact me or have your staff contact Cynthia Dougherty, Director of the Office of Ground Water and Drinking Water at (202) 564-3750, or Ronald Bergman, Associate Chief of the Protection Branch in the Office of Ground Water and Drinking Water, at (202) 564-3823.

Attachment

cc: Regional Drinking Water Branch Chiefs
        James Taft, Association of State Drinking Water Administrators

Attachment A
Tiering Classification System for Selection of Monitoring Sites

Tiering Classification	
If you are a Community Water System	*If you are an Non-transient Noncommunity Water System*
Tier 1 sampling sites are single family structures: with copper pipes with lead solder installed after 1982 *(but before the effective date of your State's lead ban)* or contain lead pipes; and/or that are served by a lead service line. *Note :* When multiple-family residences (MFRs) comprise at least 20% of the structures served by a water system, the system may count them as Tier 1 sites. **Tier 2** sampling sites consist of buildings, including MFRs: with copper pipes with lead solder installed after 1982 *(but before effective date of your State's lead ban)* or contain lead pipes; and/or that are served by a lead service line. **Tier 3** sampling sites are single family structures w/ copper pipes having lead solder installed before 1983.	**Tier 1** sampling sites consist of buildings: with copper pipes with lead solder installed after 1982 *(but before the effective date of your State's lead ban)*or contain lead pipes; and/or that are served by a lead service line. **Tier 2** sampling sites consist of buildings with copper pipes with lead solder installed before 1983. **Tier 3**: Not applicable.
Note: ■ All States were required to ban the use of lead solder in all public water systems, and all homes and buildings connected to such systems by June 1988 (most States adopted the ban in 1987 or 1988). Contact the Drinking Water Program in your State to find out the effective date. ■ A community water system with insufficient tier 1, tier 2 and tier 3 sampling sites, or an non-transient noncommunity water system with insufficient tier 1 and tier 2 sites, shall complete its sampling pool with representative sites throughout the distribution system. For the purposes of this paragraph, a representative site is a site in which the plumbing materials used at that site would be commonly found at other sites served by the water system. [40 CFR 141.86(a)(5) and (7)]	

Source: *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems*, EPA-816-R-02-009

⊕**EPA**

Total Coliform Rule:
A Quick Reference Guide

Overview of the Rule

Title	**Total Coliform Rule (TCR)** **54 FR 27544-27568, June 29, 1989, Vol. 54, No. 124**[1]
Purpose	Improve public health protection by reducing fecal pathogens to minimal levels through control of total coliform bacteria, including fecal coliforms and *Escherichia coli (E. coli)*.
General Description	Establishes a maximum contaminant level (MCL) based on the presence or absence of total coliforms, modifies monitoring requirements including testing for fecal coliforms or *E. coli,* requires use of a sample siting plan, and also requires sanitary surveys for systems collecting fewer than five samples per month.
Utilities Covered	The TCR applies to all public water systems.

Public Health Benefits

Implementation of the TCR has resulted in . . .	▸ Reduction in risk of illness from disease causing organisms associated with sewage or animal wastes. Disease symptoms may include diarrhea, cramps, nausea, and possibly jaundice, and associated headaches and fatigue.

What are the Major Provisions?

ROUTINE Sampling Requirements

▸ Total coliform samples must be collected at sites which are representative of water quality throughout the distribution system according to a written sample siting plan subject to state review and revision.

▸ Samples must be collected at regular time intervals throughout the month except groundwater systems serving 4,900 persons or fewer may collect them on the same day.

▸ Monthly sampling requirements are based on population served (see table on next page for the minimum sampling frequency).

▸ A reduced monitoring frequency may be available for systems serving 1,000 persons or fewer and using only ground water if a sanitary survey within the past 5 years shows the system is free of sanitary defects (the frequency may be no less than 1 sample/quarter for community and 1 sample/year for non-community systems).

▸ Each total coliform-positive routine sample must be tested for the presence of fecal coliforms or *E. coli*.

▸ If any routine sample is total coliform-positive, repeat samples are required.

REPEAT Sampling Requirements

▸ Within 24 hours of learning of a total coliform-positive ROUTINE sample result, at least 3 REPEAT samples must be collected and analyzed for total coliforms:

▸ One REPEAT sample must be collected from the same tap as the original sample.
▸ One REPEAT sample must be collected within five service connections upstream.
▸ One REPEAT sample must be collected within five service connections downstream.
▸ Systems that collect 1 ROUTINE sample per month or fewer must collect a 4th REPEAT sample.

▸ If any REPEAT sample is total coliform-positive:

▸ The system must analyze that total coliform-positive culture for fecal coliforms or *E.coli*.
▸ The system must collect another set of REPEAT samples, as before, unless the MCL has been violated and the system has notified the state.

Additional ROUTINE Sample Requirements

▸ A positive ROUTINE or REPEAT total coliform result requires a minimum of five ROUTINE samples be collected the following month the system provides water to the public unless waived by the state.

[1] The June 1989 Rule was revised as follows: Corrections and Technical Amendments, 6/19/90 and Partial Stay of Certain Provisions (Variance Criteria) 56 FR 1556-1557, Vol 56, No 10.

Note: The TCR is currently undergoing the 6 year review process and may be subject to change.

Public Water System ROUTINE Monitoring Frequencies

Population	Minimum Samples/ Month	Population	Minimum Samples/ Month	Population	Minimum Samples/ Month
25-1,000*	1	21,501-25,000	25	450,001-600,000	210
1,001-2,500	2	25,001-33,000	30	600,001-780,000	240
2,501-3,300	3	33,001-41,000	40	780,001-970,000	270
3,301-4,100	4	41,001-50,000	50	970,001-1,230,000	300
4,101-4,900	5	50,001-59,000	60	1,230,001-1,520,000	330
4,901-5,800	6	59,001-70,000	70	1,520,001-1,850,000	360
5,801-6,700	7	70,001-83,000	80	1,850,001-2,270,000	390
6,701-7,600	8	83,001-96,000	90	2,270,001-3,020,000	420
7,601-8,500	9	96,001-130,000	100	3,020,001-3,960,000	450
8,501-12,900	10	130,001-220,000	120	≥ 3,960,001	480
12,901-17,200	15	220,001-320,000	150		
17,201-21,500	20	320,001-450,000	180		

*Includes PWSs which have at least 15 service connections, but serve <25 people.

What are the Other Provisions?

Systems collecting fewer than 5 ROUTINE samples per month . . .	Must have a sanitary survey every 5 years (or every 10 years if it is a non-community water system using protected and disinfected ground water).**
Systems using surface water or ground water under the direct influence of surface water (GWUDI) and meeting filtration avoidance criteria . . .	Must collect and have analyzed one coliform sample each day the turbidity of the source water exceeds 1 NTU. This sample must be collected from a tap near the first service connection.

** As per the IESWTR, states must conduct sanitary surveys for community surface water and GWUDI systems in this category every 3 years (unless reduced by the state based on outstanding performance).

How is Compliance Determined?

- Compliance is based on the presence or absence of total coliforms.
- Compliance is determined each calendar month the system serves water to the public (or each calendar month that sampling occurs for systems on reduced monitoring).
- The results of ROUTINE and REPEAT samples are used to calculate compliance.

A Monthly MCL Violation is Triggered if:

A system collecting fewer than 40 samples per month . . .	Has greater than 1 ROUTINE/REPEAT sample per month which is total coliform-positive.
A system collecting at least 40 samples per month . . .	Has greater than 5.0 percent of the ROUTINE/REPEAT samples in a month total coliform-positive.

An Acute MCL Violation is Triggered if:

Any public water system . . .	Has any fecal coliform- or *E. coli*-positive REPEAT sample *or* has a fecal coliform- or *E. coli*-positive ROUTINE sample followed by a total coliform-positive REPEAT sample.

What are the Public Notification and Reporting Requirements?

For a Monthly MCL Violation	- The violation must be reported to the state no later than the end of the next business day after the system learns of the violation. - The public must be notified within 14 days. [2]
For an Acute MCL Violation	- The violation must be reported to the state no later than the end of the next business day after the system learns of the violation. - The public must be notified within 72 hours. [2]
Systems with ROUTINE or REPEAT samples that are fecal coliform- or *E. coli*-positive . . .	Must notify the state by the end of the day they are notified of the result or by the end of the next business day if the state office is already closed.

United States
Environmental Protection
Agency

Office of Water
(4606)

EPA 816-F-01-010
May 2001
www.epa.gov/safewater

♦EPA

Stage 1 Disinfectants and Disinfection Byproducts Rule:
A Quick Reference Guide

Overview of the Rule

Title	Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) 63 FR 69390 - 69476, December 16, 1998, Vol. 63, No. 241 Revisions to the Interim Enhanced Surface Water Treatment Rule (IESWTR), the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR), and Revisions to State Primacy Requirements to Implement the Safe Drinking Water Act (SDWA) Amendments 66 FR 3770, January 16, 2001, Vol 66, No. 29
Purpose	Improve public health protection by reducing exposure to disinfection byproducts. Some disinfectants and disinfection byproducts (DBPs) have been shown to cause cancer and reproductive effects in lab animals and suggested bladder cancer and reproductive effects in humans.
General Description	The Stage 1 DBPR is the first of a staged set of rules that will reduce the allowable levels of DBPs in drinking water. The new rule establishes seven new standards and a treatment technique of enhanced coagulation or enhanced softening to further reduce DBP exposure. The rule is designed to limit capital investments and avoid major shifts in disinfection technologies until additional information is available on the occurrence and health effects of DBPs.
Utilities Covered	The Stage 1 DBPR applies to all sizes of community water systems and nontransient noncommunity water systems that add a disinfectant to the drinking water during any part of the treatment process and transient noncommunity water systems that use chlorine dioxide.

Public Health Benefits

Implementation of the Stage 1 DBPR will result in . . .	▸ As many as 140 million people receiving increased protection from DBPs. ▸ 24 percent average reduction nationally in trihalomethane levels. ▸ Reduction in exposure to the major DBPs from use of ozone (DBP = bromate) and chlorine dioxide (DBP = chlorite).
Estimated impacts of the Stage 1 DBPR include . . .	▸ National capital costs: $2.3 billion ▸ National total annualized costs to utilities: $684 million ▸ 95 percent of households will incur an increase of less than $1 per month. ▸ 4 percent of households will incur an increase of $1-10 per month. ▸ <1 percent of households will incur an increase of $10-33 per month.

Critical Deadlines and Requirements

For Drinking Water Systems

January 1, 2002	Surface water systems and ground water systems under the direct influence of surface water serving ≥ 10,000 people must comply with the Stage 1 DBPR requirements.
January 1, 2004	Surface water systems and ground water systems under the direct influence of surface water serving < 10,000, and all ground water systems must comply with the Stage 1 DBPR requirements.

For States

December 16, 2000	States submit Stage 1 DBPR primacy revision applications to EPA (triggers interim primacy).
December 16, 2002	Primacy extension deadline - all states with an extension must submit primacy revision applications to EPA.

Regulated Contaminants/Disinfectants

Regulated Contaminants	MCL (mg/L)	MCLG (mg/L)	Regulated Disinfectants	MRDL* (mg/L)	MRDLG* (mg/L)
Total Trihalomethanes (TTHM)	0.080				
Chloroform Bromodichloromethane Dibromochloromethane Bromoform		- zero 0.06 zero	**Chlorine**	4.0 as Cl$_2$	4
Five Haloacetic Acids (HAA5)	0.060		**Chloramines**	4.0 as Cl$_2$	4
Monochloroacetic acid Dichloroacetic acid Trichloroacetic acid Bromoacetic acid Dibromoacetic acid		- zero 0.3 - -	**Chlorine dioxide**	0.8	0.8
Bromate (plants that use ozone)	0.010	zero	*Stage 1 DBPR includes maximum residual disinfectant levels (MRDLs) and maximum residual disinfectant level goals (MRDLGs) which are similar to MCLs and MCLGs, but for disinfectants.		
Chlorite (plants that use chlorine dioxide)	1.0	0.8			

Treatment Technique

Enhanced coagulation/enhanced softening to improve removal of DBP precursors (See Step 1 TOC Table) for systems using conventional filtration treatment.

Step 1 TOC Table - Required % Removal of TOC

Source Water TOC (mg/L)	Source Water Alkalinity, mg/L as CaCO$_3$		
	0-60	> 60-120	> 120
> 2.0 to 4.0	35.0%	25.0%	15.0%
> 4.0 to 8.0	45.0%	35.0%	25.0%
> 8.0	50.0%	40.0%	30.0%

[1] Systems meeting at least one of the alternative compliance criteria in the rule are not required to meet the removals in this table.

[2] Systems practicing softening must meet the TOC removal requirements in the last column to the right

Routine Monitoring Requirements

	Coverage	Monitoring Frequency	Compliance
TTHM/HAA5	Surface and ground water under the direct influence of surface water serving ≥ 10,000	4/plant/quarter	Running annual average
	Surface and ground water under the direct influence of surface water serving 500 - 9,999	1/plant/quarter	Running annual average
	Surface and ground water under the direct influence of surface water serving < 500	1/plant/year in month of warmest water temperature**	Running annual average of increased monitoring
	Ground water serving ≥ 10,000	1/plant/quarter	Running annual average
	Ground water serving < 10,000	1/plant/year in month of warmest water temperature**	Running annual average of increased monitoring
Bromate	Ozone plants	Monthly	Running annual average
Chlorite	Chlorine dioxide plants	Daily at entrance to distribution system; monthly in distribution system	Daily/follow-up monitoring
Chlorine dioxide	Chlorine dioxide plants	Daily at entrance to distribution system	Daily/follow-up monitoring
Chlorine/Chloramines	All systems	Same location and frequency as TCR sampling	Running annual average
DBP precursors	Conventional filtration	Monthly for total organic carbon and alkalinity	Running annual average

** System must increase monitoring to 1 sample per plant per quarter if an MCL is exceeded.

For additional information on the Stage 1 DBPR

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA web site at www.epa.gov/safewater; or contact your State drinking water representative.

Additional material is available at www.epa.gov/safewater/mdbp/implement.html.

United States
Environmental Protection
Agency

Office of Water
(4606)

EPA 816-F-01-011
May 2001
www.epa.gov/safewater

⊕EPA

Interim Enhanced Surface Water Treatment Rule:
A Quick Reference Guide

Overview of the Rule

Title	**Interim Enhanced Surface Water Treatment Rule (IESWTR)** **63 FR 69478 - 69521, December 16, 1998, Vol. 63, No. 241** **Revisions to the Interim Enhanced Surface Water Treatment Rule (IESWTR), the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR), and Revisions to State Primacy Requirements to Implement the Safe Drinking Water Act (SDWA) Amendments** **66 FR 3770, January 16, 2001, Vol 66, No. 29**
Purpose	**Improve public health control of microbial contaminants, particularly *Cryptosporidium*. Prevent significant increases in microbial risk that might otherwise occur when systems implement the Stage 1 Disinfectants and Disinfection Byproducts Rule.**
General Description	**Builds upon treatment technique approach and requirements of the 1989 Surface Water Treatment Rule. Relies on existing technologies currently in use at water treatment plants.**
Utilities Covered	**Sanitary survey requirements apply to all public water systems using surface water or ground water under the direct influence of surface water, regardless of size. All remaining requirements apply to public water systems that use surface water or ground water under the direct influence of surface water and serve 10,000 or more people.**

Major Provisions

Regulated Contaminants

Cryptosporidium	▸ **Maximum contaminant level goal (MCLG) of zero.** ▸ **99 percent (2-log) physical removal for systems that filter.** ▸ **Include in watershed control program for unfiltered systems.**
Turbidity Performance Standards	**Conventional and direct filtration combined filter effluent:** ▸ **£ 0.3 nephelometric turbidity units (NTU) in at least 95 percent of measurements taken each month.** ▸ **Maximum level of 1 NTU.**

Turbidity Monitoring Requirements
(Conventional and Direct Filtration)

Combined Filter Effluent	▸ **Performed every 4 hours to ensure compliance with turbidity performance standards.**
Individual Filter Effluent	▸ **Performed continuously (every 15 minutes) to assist treatment plant operators in understanding and assessing filter performance.**

Additional Requirements

▸ **Disinfection profiling and benchmarking.**

▸ **Construction of new uncovered finished water storage facilities prohibited.**

▸ **Sanitary surveys, conducted by the state, for all surface water and ground water under the direct influence of surface water systems regardless of size (every 3 years for community water systems and every 5 years for noncommunity water systems).**

Profiling and Benchmarking

Public water systems must evaluate impacts on microbial risk before changing disinfection practices to ensure adequate protection is maintained. The three major steps are:

- Determine if a public water system needs to profile based on TTHM and HAA5 levels (applicability monitoring)

- Develop a disinfection profile that reflects daily *Giardia lamblia* inactivation for at least a year (systems using ozone or chloramines must also calculate inactivation of viruses)

- Calculate a disinfection benchmark (lowest monthly inactivation) based on the profile and consult with the state prior to making a significant change to disinfection practices

Critical Deadlines and Requirements

For Drinking Water Systems

February 16, 1999	Construction of uncovered finished water reservoirs is prohibited.
March 1999	Public water systems lacking ICR or other occurrence data begin 4 quarters of applicability monitoring for TTHM and HAA5 to determine if disinfection profiling is necessary.
April 16, 1999	Systems that have 4 consecutive quarters of HAA5 occurrence data that meet the TTHM monitoring requirements must submit data to the state to determine if disinfection profiling is necessary.
December 31, 1999	Public water systems with ICR data must submit it to states to determine if disinfection profiling is necessary.
April 1, 2000	Public water systems must begin developing a disinfection profile if their annual average (based on 4 quarters of data) for TTHM is greater than or equal to 0.064 mg/L or HAA5 is greater than or equal to 0.048 mg/L.
March 31, 2001	Disinfection profile must be complete.
January 1, 2002	Surface water systems or ground water under the direct influence of surface water systems serving 10,000 or more people must comply with all IESWTR provisions (e.g., turbidity standards, individual filter monitoring).

For States

December 16, 2000	States submit IESWTR primacy revision applications to EPA (triggers interim primacy).
January 2002	States begin first round of sanitary surveys.
December 16, 2002	Primacy extension deadline - all states with an extension must submit primacy revision applications to EPA.
December 2004	States must complete first round of sanitary surveys for community water systems.
December 2006	States must complete first round of sanitary surveys for noncommunity water systems.

Public Health Benefits

Implementation of the IESWTR will result in . . .	- Increased protection against gastrointestinal illnesses from *Cryptosporidium* and other pathogens through improvements in filtration. - Reduced likelihood of endemic illness from *Cryptosporidium* by 110,000 to 463,000 cases annually. - Reduced likelihood of outbreaks of cryptosporidiosis.
Estimated impacts of the IESWTR include . . .	- National total annualized cost: $307 million - 92 percent of households will incur an increase of less than $1 per month. - Less than 1 percent of households will incur an increase of more than $5 per month (about $8 per month).

EPA
United States
Environmental Protection
Agency

Long Term 1 Enhanced Surface Water Treatment Rule: A Quick Reference Guide

Overview of the Rule

Title	Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) 67 FR 1812, January 14, 2002, Vol. 67, No. 9
Purpose	Improve public health protection through the control of microbial contaminants, particularly *Cryptosporidium*. Prevent significant increases in microbial risk that might otherwise occur when systems implement the Stage 1 Disinfectants and Disinfection Byproducts Rule.
General Description	Builds upon the requirements of the 1989 Surface Water Treatment Rule (SWTR). Smaller system counterpart of the Interim Enhanced Surface Water Treatment Rule (IESWTR).
Utilities Covered	Public water systems that use surface water or ground water under the direct influence of surface water (GWUDI) and serve fewer than 10,000 people.

Major Provisions

Control of *Cryptosporidium*	▸ The maximum contaminant level goal (MCLG) is set at zero. ▸ Filtered systems must physically remove 99% (2-log) of *Cryptosporidium*. ▸ Unfiltered systems must update their watershed control programs to minimize the potential for contamination by *Cryptosporidium* oocysts. ▸ *Cryptosporidium* is included as an indicator of GWUDI.
Combined Filter Effluent (CFE) Turbidity Performance Standards	*Specific CFE turbidity requirements depend on the type of filtration used by the system.* **Conventional and direct filtration:** ▸ £0.3 nephelometric turbidity units (NTU) in at least 95% of measurements taken each month. ▸ Maximum level of turbidity: 1 NTU. **Slow sand and diatomaceous earth (DE) filtration:** ▸ Continue to meet CFE turbidity limits specified in the SWTR: • 1 NTU in at least 95% of measurements taken each month. • Maximum level of turbidity: 5 NTU. **Alternative technologies (other than conventional, direct, slow sand, or DE):** ▸ Turbidity levels are established by the State based on filter demonstration data submitted by the system. • State-set limits must not exceed 1 NTU (in at least 95% of measurements) or 5 NTU (maximum).
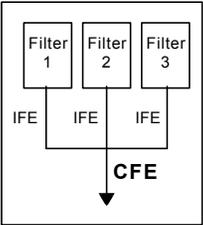
Filter 1   Filter 2   Filter 3
IFE   IFE   IFE
CFE

Turbidity Monitoring Requirements

Combined Filter Effluent	▸ Performed at least every 4 hours to ensure compliance with CFE turbidity performance standards.[1]
Individual Filter Effluent (IFE) (for systems using conventional and direct filtration only)	*Since the CFE may meet regulatory requirements even though one filter is producing high turbidity water, the IFE is measured to assist conventional and direct filtration treatment plant operators in understanding and assessing individual filter performance.* ▸ Performed continuously (recorded at least every 15 minutes). ▸ Systems with two or fewer filters may conduct continuous monitoring of CFE turbidity in place of individual filter effluent turbidity monitoring. ▸ Certain follow-up actions are required if the IFE turbidity (or CFE for systems with two filters) exceeds 1.0 NTU in 2 consecutive readings or more (i.e., additional reporting, filter self-assessments, and/or comprehensive performance evaluations (CPEs)).

For additional information on the LT1ESWTR

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA web site at www.epa.gov/safewater/mdbp/lt1eswtr.html; or contact your State drinking water representative.

[1] This frequency may be reduced by the State to once per day for systems using slow sand/alternative filtration or for systems serving 500 persons or fewer regardless of the type of filtration used.

Disinfection Profiling and Benchmarking Requirements

Community and non-transient non-community public water systems must evaluate impacts on microbial risk before changing disinfection practices to ensure adequate microbial protection is maintained. This is accomplished through a process called disinfection profiling and benchmarking.

What are the disinfection profiling and benchmarking requirements?

▶ Systems must develop a disinfection profile, which is a graphical compilation of weekly inactivation *of Giardia lamblia*, taken on the same calendar day each week over 12 consecutive months. (Systems using chloramines, ozone, or chlorine dioxide for primary disinfection must also calculate inactivation of viruses). Results must be available for review by the State during sanitary surveys.

▶ A State may deem a profile unnecessary if the system has sample data collected after January 1, 1998–during the month of warmest water temperature and at maximum residence time in the distribution system–indicating TTHM levels are below 0.064 mg/L <u>and</u> HAA5 levels are below 0.048 mg/L.

▶ Prior to making a significant change to disinfection practices, systems required to develop a profile must calculate a disinfection benchmark and consult with the State. The benchmark is the calculation of the lowest monthly average of inactivation based on the disinfection profile.

Additional Requirements

▶ Construction of new uncovered finished water reservoirs is prohibited.

Critical Deadlines and Requirements

For Drinking Water Systems

March 15, 2002	Construction of uncovered finished reservoirs is prohibited.
July 1, 2003	No later than this date, systems serving between 500-9,999 persons must report to the State: ▶ Results of optional monitoring which show levels of TTHM < 0.064 mg/L <u>and</u> HAA5 < 0.048 mg/L, OR ▶ System has started profiling.
January 1, 2004	No later than this date, systems serving fewer than 500 persons must report to the State: ▶ Results of optional monitoring which show levels of TTHM < 0.064 mg/L <u>and</u> HAA5 < 0.048 mg/L, OR ▶ System has started profiling.
June 30, 2004	Systems serving between 500 and 9,999 persons must complete their disinfection profile unless the State has determined it is unnecessary.
December 31, 2004	Systems serving fewer than 500 persons must complete their disinfection profile unless the State has determined it is unnecessary.
January 14, 2005	Surface water systems or GWUDI systems serving fewer than 10,000 people must comply with the applicable LT1ESWTR provisions (e.g., turbidity standards, individual filter monitoring, *Cryptosporidium* removal requirements, updated watershed control requirements for unfiltered systems).

For States

January 2002	As per the IESWTR, States begin first round of sanitary surveys (at least every 3 years for community water systems and every 5 years for non-community water systems).
October 14, 2003	States are encouraged to submit final primacy applications to EPA.
January 14, 2004	Final primacy applications must be submitted to EPA unless granted an extension.
December 2004	States must complete first round of sanitary surveys for community water systems (as per the IESWTR).
January 14, 2006	Final primacy revision applications from States with approved 2-year extension agreements must be submitted to EPA.
December 2006	States must complete first round of sanitary surveys for non-community water systems (as per the IESWTR).

Public Health Benefits

Implementation of the LT1ESWTR will result in . . .	▶ Increased protection against gastrointestinal illnesses from *Cryptosporidium* and other pathogens through improvements in filtration. ▶ Reduced likelihood of endemic illness from *Cryptosporidium* by an estimated 12,000 to 41,000 cases annually. ▶ Reduced likelihood of outbreaks of cryptosporidiosis.
Estimated impacts of the LT1ESWTR include . . .	▶ National total annualized cost: $39.5 million. ▶ 90% of affected households will incur an increase of less than $1.25 per month. ▶ One percent of affected households are likely to incur an increase of more than $10 per month.

♻EPA

Filter Backwash Recycling Rule: A Quick Reference Guide

Overview of the Rule

Title	**Filter Backwash Recycling Rule (FBRR)** **66 FR 31086, June 8, 2001, Vol. 66, No. 111**
Purpose	**Improve public health protection by assessing and changing, where needed, recycle practices for improved contaminant control, particularly microbial contaminants.**
General Description	**The FBRR requires systems that recycle to return specific recycle flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the state.**
Utilities Covered	**Applies to public water systems that use surface water or ground water under the direct influence of surface water, practice conventional or direct filtration, and recycle spent filter backwash, thickener supernatant, or liquids from dewatering processes.**

Public Health Benefits

Implementation of FBRR will result in . . .	▸ **Reduction in risk of illness from microbial pathogens in drinking water, particularly *Cryptosporidium*.**
Estimated impacts of the FBRR include . . .	▸ **FBRR will apply to an estimated 4,650 systems serving 35 million Americans.** ▸ **Fewer than 400 systems are expected to require capital improvements.** ▸ **Annualized capital costs incurred by public water systems associated with recycle modifications are estimated to be $5.8 million.** ▸ **Mean annual cost per household is estimated to be less than $1.70 for 99 percent of the affected households and between $1.70 and $100 for the remaining one percent of affected households.**

Conventional and Direct Filtration

▸ **Conventional filtration, as defined in 40 CFR 141.2, is a series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particulate removal. Conventional filtration is the most common type of filtration.**

▸ **Direct filtration, as defined in 40 CFR 141.2, is a series of processes including coagulation and filtration, but excluding sedimentation, and resulting in substantial particulate removal. Typically, direct filtration can be used only with high-quality raw water that has low levels of turbidity and suspended solids.**

Recycle Flows

- <u>Spent Filter Backwash Water</u> - A stream containing particles that are dislodged from filter media when water is forced back through a filter (backwashed) to clean the filter.
- <u>Thickener Supernatant</u> - A stream containing the decant from a sedimentation basin, clarifier or other unit that is used to treat water, solids, or semi-solids from the primary treatment processes.
- <u>Liquids From Dewatering Processes</u> - A stream containing liquids generated from a unit used to concentrate solids for disposal.

Critical Deadlines and Requirements

For Drinking Water Systems

December 8, 2003	Submit recycle notification to the state.
June 8, 2004	Return recycle flows through the processes of a system's existing conventional or direct filtration system or an alternate recycle location approved by the state (a 2-year extension is available for systems making capital improvements to modify recycle location). Collect recycle flow information and retain on file.
June 8, 2006	Complete all capital improvements associated with relocating recycle return location (if necessary).

For States

June 8, 2003	States submit FBRR primacy revision application to EPA (triggers interim primacy).
June 8, 2005	Primacy extension deadline - all states with an extension must submit primacy revision applications to EPA.

What does a recycle notification include?

- Plant schematic showing origin of recycle flows, how recycle flows are conveyed, and return location of recycle flows.
- Typical recycle flows (gpm), highest observed plant flow experienced in the previous year (gpm), and design flow for the treatment plant (gpm).
- State-approved plant operating capacity (if applicable).

What recycle flow information does a system need to collect and retain on file?

- Copy of recycle notification and information submitted to the state.
- List of all recycle flows and frequency with which they are returned.
- Average and maximum backwash flow rates through filters, and average and maximum duration of filter backwash process (in minutes).
- Typical filter run length and written summary of how filter run length is determined.
- Type of treatment provided for recycle flows.
- Data on the physical dimension of the equalization and/or treatment units, typical and maximum hydraulic loading rates, types of treatment chemicals used, average dose, frequency of use, and frequency at which solids are removed, if applicable.

For additional information on the FBRR

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA web site at www.epa.gov/safewater; or contact your state drinking water representative.

Additional material is available at www.epa.gov/safewater/ filterbackwash.html.

1 **Appendix B**
2 **Case Studies**

1
2   This page intentionally left blank.

1
2

Case Studies in this Guidance Manual and Issues they Address

Case Study No.	Treatment/Issue Addressed	Utility Name	Case Study Location	Population Served	Average Annual Treatment Plant (MGD) Production	Source Water	Page	Section Where It is Referenced in the Manual
1	Moving the Point of Chlorination Downstream	Owenton Water Works and Kentucky American TriVillage	Owenton, Kentucky	<10,000	1	Surface Water (reservoir)	B-7	3.3
2	Decreasing pH	Public Utility District #1	Skagit County, Washington	70,000	12	Surface Water (reservoir)	B-13	3.4
3	Presedimentation	Kansas City Water Services	Kansas City, Missouri	>600,000	240	Surface Water (river, ground water under the direct influence of surface water)	B-21	3.6
4	Switching Coagulants	Hillsborough River Water Treatment Plant	Tampa, Florida	>450,000	100	Surface Water (river)	B-25	3.7
5	Enhanced Coagulation - Problems with Copper Pitting	Washington Suburban Sanitary Commission	Montgomery and Prince Georges County, Maryland	1,600,000	167	Surface Water (rivers)	B-33	3.7

Case Study No.	Treatment/Issue Addressed	Utility Name	Case Study Location	Population Served	Average Annual Treatment Plant (MGD) Production	Source Water	Page	Section Where It is Referenced in the Manual
6	Enhanced Coagulation - Managing Radioactive Residuals	Allen Water Filtration Plant	Englewood, Colorado	48,000	8.5	Surface Water (river, creek, diversions)	B-39	3.7
7	GAC for TOC Removal	Higginsville Water Treatment Plant	Higginsville, Missouri	<10,000	2	Surface Water (reservoir)	B-45	4.1
8	Nanofiltration Membrane Technology for TOC Removal	PBCWUD Water Treatment Plant #9	West Palm Beach, Florida	132,000	27	Surface Water (surficial aquifer)	B-49	4.3
9	Modifying Chloramination Practices to Address Nitrification Issues	Ann Arbor Utilities	Ann Arbor, Michigan	115,000	20	Surface Water (river, wells)	B-57	5.1
10	Ozonation	Ann Arbor Utilities	Ann Arbor, Michigan	115,000	20	Surface Water (river, wells)	B-63	5.2
11	Ozonation and Biological Filtration	Sweeney Water Treatment Plant	Wilmington, North Carolina	75,000	25	Surface Water (river)	B-71	5.2

Case Study No.	Treatment/Issue Addressed	Utility Name	Case Study Location	Population Served	Average Annual Treatment Plant (MGD) Production	Source Water	Page	Section Where It is Referenced in the Manual
12	UV Disinfection	Poughkeepsie Water Treatment Facility	Poughkeepsie, New York	75,000	16	Surface Water (river)	B-77	5.3
13	Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection	Gulf Coast Water Authority	Texas City, Texas	92,000	12	Surface Water (river)	B-81	5.4
14	Chlorine Dioxide for Primary Disinfection and Chloramines for Residual Disinfection	Village of Waterloo Water Treatment Plant	Waterloo, New York	<10,000	2	Surface Water (lake)	B-89	5.5

1

1   This page intentionally left blank.

Case Study #1
Moving the Point of Chlorination
Owenton Water Works and Kentucky American TriVillage
Owenton, Kentucky

This case study provides an example of how two small PWSs, both using water treated by the same conventional filtration plant, worked together to change chlorination practices to their existing treatment and operations to reduce TTHM. Reducing TTHM was the primary objective, due to the timing of this work beginning in late 1999 prior to regulatory limits for these systems serving a combined population under 10,000.

Changes described here took place primarily over the first 6 months of 2000 and were made in a series of carefully planned and monitored steps in close consultation with the state regulatory officials and with knowledge of available EPA regulations and guidance. This work has also been successful in reducing HAA5s as these systems completed the first year (2004) in compliance with the 80/60 THM/HAA limits.

Prior to moving the point of chlorination, the following steps were carried out:

1) Enhanced coagulation was initiated at lower pH to improve TOC removal and sodium hydroxide (caustic soda) was added to maintain distribution corrosion control.

2) Potassium permanganate feed to the raw water was optimized to control source water manganese and to provide reliable pre-oxidation in anticipation of moving the chlorine application point.

3) In-plant chlorine disinfection contact time was assessed and operations revised to increase chlorine retention time in the plant clearwell. This step included trending 12 months of disinfection data in the plant and consultation with the state. The state provided a list of additional source monitoring (microbiological and other related water quality parameters from source through distribution) to be conducted prior to and following the change in chlorine application point.

The point of chlorination was then moved by turning off the chlorine feed to the rapid mix portion of plant treatment and increasing chlorine at the application points just before and after the filters to provide the required residuals in the plant clearwell and through distribution.

This case study is documented in Routt (2004) and Routt and Pizzi (2000). Readers may refer to those references for more details. Updates were also provided for this case study by J. Routt in January 2005.

1   **Introduction**
2
3   The Owenton City Water Works operates a conventional 1 million gallons per day
4   treatment plant that uses water from an algae-rich reservoir. Approximately half of the water
5   that is produced by the Owenton facility is sold to Kentucky American Water Northern Division
6   (TriVillage), a privately owned water system. Owenton delivers the remainder of the water in its
7   own distribution network. Together, the two systems serve fewer than 10,000 people. However,
8   for several years prior to this work (which began in late 1999), both systems had been regularly
9   issuing state-required health-based public notices due to elevated TTHM.
10
11   To define the factors contributing to the elevated DBPs, Kentucky American Water, in
12   cooperation with the City of Owenton, collected water quality data from both systems. These
13   data showed that the most effective solution to the elevated DBPs would be to switch to a source
14   water of higher quality. Switching source waters, however, was understood to be a long-term,
15   expensive project that would require designing and building new intake and transmission
16   facilities. In the meantime, the systems decided to make operational changes to improve water
17   quality before the completion of the new intake and transmission lines.
18
19   **The Original Treatment Process at the Owenton WTP**
20
21   The system used a high TOC, high alkalinity source water prone to fluctuating
22   manganese levels. Before treatment changes were made, chlorine was being added at the rapid
23   mix and again at booster stations to provide required free chlorine residuals through the
24   distribution system. The treatment plant was using alum-lime coagulation with a pH of
25   approximately 7.8, and was achieving less than 28 percent TOC removal. This TOC removal
26   efficiency would not meet the Step 1 requirements of the Stage 1 D/ DBPR for the system. In
27   addition, monitoring showed that TTHM levels were elevated leaving the treatment plant and
28   increased substantially with retention time and re- chlorination through the distribution network.
29
30   **Simultaneous Compliance Issues Faced by the Utilities**
31
32   The combined systems had high TTHM concentrations and were faced with the challenge
33   of complying with upcoming Stage 1 D/DBPR and Stage 2 DBPR requirements. Priorities and
34   plans had to be clearly set to help ensure ongoing compliance with other regulations that stood to
35   be impacted by treatment changes to reduce DBPs–such as SWTR disinfection and filtered
36   turbidity requirements, LCR corrosion control requirements and TCR microbiological control
37   requirements. To that end, the systems embarked upon a cooperative effort to proceed through
38   steps to improve DBPs for the short term–using existing source water and treatment and
39   distribution facilities–while keeping the multiple regulatory requirements in mind.
40

Steps Taken by the Utilities

Profiles of TOC removal, TTHM formation, and disinfection were collected through the plant and distribution system. These process profiles showed that TOC was not being effectively removed, and that high levels of TTHM and HAA5 were being formed in the treatment plant.

Treatment changes, therefore, consisted of maximizing TOC removal and optimizing chlorine disinfectant application. Operational changes were made in a phased process over several months, with state approval granted for each step. The results of each step were evaluated before the systems proceeded to the next phase.

Enhancing Coagulation

The removal of TOC was increased by making several relatively simple changes to the coagulation process in the Owenton treatment plant. Coagulation and TOC removal were enhanced by ceasing pre-lime application, and approximately doubling the alum dose to lower the treated water pH to 6.9. The change in coagulation chemicals required addition of a postfiltration caustic feed (sodium hydroxide) to adjust the finished water's pH to 7.6-7.8 for distribution system corrosion control.

In addition, a switch from alum to ferric chloride was made in order to improve the solids handling in the plant's solids-contact upflow clarifier. Ferric chloride was expected to produce good TOC removal with less chemical, and to produce a more stable floc, less prone to upset and carry-over onto filters. These expectations were met.

Changes to the coagulation process roughly doubled the TOC removal and decreased chlorine demand. Chlorine residuals persisted noticeably longer in the distribution system, which allowed the systems to reduce their re- chlorination doses at the master metering points in the distribution system. Levels of TTHM, however, were decreased by only 15 percent. The next step was to evaluate plant disinfection and seek state approval to move the point of chlorination to later in the treatment process.

Converting to Top-of-Filter Chlorination

Prior to moving the chlorination point, the Owenton plant was thoroughly assessed for adequate disinfection contact time. Tracer studies were conducted of the clearwell, which is well-baffled, and operational guidelines were changed to increase the minimum water level in the clearwell which effectively increased the chlorine disinfection contact time with filtered water. This was to offset contact time that would be lost when chlorine application was moved from rapid mix to the top of the filters. Potassium permanganate pretreatment procedures were revised to incorporate regular demand tests to improve dosing accuracy and to reduce chlorine oxidant demand. It was emphasized that, once the point of chlorination was moved to the top of the filter, permanganate would be the only pre-oxidant. Therefore, optimization would be

1   critical to good coagulation of natural organics and to prevent manganese carryover when
2   treating the fluctuating dissolved manganese in the source water.
3
4   The state approved the system's proposal to switch to ferric chloride coagulant, followed
5   by post-caustic for corrosion control, and moving the point of chlorination to the top of the
6   filters. The changes were made in sequence and with close supervision and monitoring. The
7   change in point of chlorination was approved with the contingency that additional testing would
8   be conducted before and after the change, in order to verify adequate disinfection and good
9   overall water quality. This additional testing included TOC and organic nitrogen source water
10 monitoring, as well as heterotrophic and total coliform bacteria monitoring through the treatment
11 plant and distribution network.
12
13 *Optimization of Booster Chlorination*
14
15   In addition to the changes made at the Owenton treatment plant, both water systems have
16 worked to optimize their distribution systems, and the purchaser, TriVillage, has optimized
17 chlorine doses at the booster stations. The reduction in finished water TOC leaving the Owenton
18 plant has allowed for a reduction in the amount of booster chlorine needed to maintain a residual
19 throughout the distribution system. Both systems have conducted additional flushing and have
20 cleaned and inspected their storage tanks. Since the changes, lead and copper action levels and
21 TCR standards have been met in both distribution systems. The systems continued to conduct
22 extra testing for TOC, DBPs, chlorine residual, and HPCs to track distribution system water
23 quality. In 2004, the TOC and DBP "compliance" testing has replaced the earlier special testing.
24
25 **Implementation and Operational Issues Faced by the Utilities**
26
27   Overall, operational changes have gone smoothly. The greatest ongoing operational
28 impacts have been related to enhanced coagulation: an increase in (approximate doubling of)
29 chemical treatment costs, along with a need for increased attention to solids removal from the
30 upflow clarifier and filter backwash settling basins.
31
32   Post-filter caustic feed has necessitated cleaning of deposits from filtered water transfer
33 pumps just downstream of the application point. This caustic buildup did not become
34 problematic until 2004 - 4 years after the initiation of caustic feed. However, utilities are advised
35 to watch for caustic clogging in mechanical devises located immediately downstream of caustic
36 application points.
37
38   In the summer of 2001, source water dissolved manganese temporarily increased to levels
39 that could not be treated by potassium permanganate alone. The resulting discolored water
40 forced the system to return to minimal prechlorination and, then, to switch briefly to
41 polyaluminum chloride as coagulant. The polyaluminum chloride coagulated well at a higher pH
42 (8.0), which improved potassium permanganate removal of the dissolved manganese and
43 eliminated the need for pre-chlorine. Within a few weeks, the source water manganese levels

dropped, and the system returned to ferric chloride coagulation at lower pH. This scenario has not recurred since.

Systems should be extremely careful when switching coagulants to ensure that they maintain consistent particle and pathogen removal. The dosage of new coagulant needed should be carefully calculated and confirmed with up-to-date jar testing using the water to be treated.

Results of the Steps Taken

Since changes were made in May 2000, filtered and distributed water quality compliance has been maintained. TTHM levels have dropped below the 0.080 mg/L standard. Testing has shown that HAA5 levels have been reduced by more than half as well. As of 2004, the first year of compliance TOC testing showed monthly removal ratios ranging from 1.96-2.35 and averaging 2.19 for the year, and the RAAs for THM and HAA5 levels were 74 and 47 ug/L, respectively.

Overall, customers have noticed that their water has improved in clarity and taste of their water, possibly due to the enhanced coagulation, and decreased chlorine demand combined with diligent attention to water quality throughout the system.

Lessons Learned From this Case Study

- Source water testing and the development of treatment plant and distribution system profiles helped the systems identify the factors that were causing DBP formation.

- By adjusting coagulation methods and the point of chlorination, while optimizing distribution operations to optimize booster chlorine use, these small surface water systems succeeded at reducing TTHM and HAA5 in the combined system, even when using a challenging source water.

- Compliance with TTHM and HAA5 standards can be achieved, without negatively impacting other regulatory programs, by implementing a combination of several carefully planned and monitored operational changes.

- Water quality improvements can be realized with short-term operational changes, and provide information useful in decision-making, pending completion of more costly, time-intensive, long-term modifications.

1 **Further Reading**
2
3   Readers can find more information about this case study in the following publications:
4
5 Routt, J.C. 2004. Lowering DBPs in Combined Systems. Opflow. 30(4): 1-7.
6
7 Routt, J.C. and N.G. Pizzi 2000. Kentucky-American Water's Cooperative, Step-wise Process of
8 Assisting Two Small Contiguous Systems in Complying with Pending D/DBP Requirements.
9 Proceedings of AWWA Water Quality Technology Conference.
10
11

1
2
3
4
5
6

Case Study #2
Modifying pH During Chlorination
Public Utility District #1
Skagit County, Washington

7   This case study provides an example of how a PWS used pH depression to reduce DBPs.
8 The depression of pH via carbon dioxide (CO_2) injection ahead of the flocculation basins also
9 produced the following results:

10
11   1) Increased coagulation efficiency and removal of DBP precursors;
12   2) Increased CT throughout the treatment plant, allowing for reduced chlorine injection;
13   and
14   3) Increased and stabilized pH levels in the distribution system by increasing the
15   buffering capacity following caustic soda addition.

16
17   The information for this case study came from Friedman and Hamilton (1997). Readers
18 should refer to that reference for further information.

19
20 **Introduction**

21
22   Public Utility District #1 of Skagit County (the District) is located in the northwest sector
23 of Washington State, approximately 70 miles south of the Canadian border and 70 miles north of
24 Seattle. The District's source of supply is Judy Reservoir, which is fed by several streams
25 originating in the Cultus Mountain watershed in Sedro-Woolley, WA. The District operates a
26 water filtration plant (WFP) designed to provide an original nominal/hydraulic flow of 12/18
27 million gallons per day (MGD) with an ultimate capacity of 21/36 MGD. Exhibit B.1 provides a
28 summary of typical water quality parameters.

29
30

Exhibit B.1 Summary of Historical Source Water Quality Data

Parameter	Units	Range of Values
Conductivity	mhos/cm	30-60
Temperature	°C	1-21
pH	standard units	6.9-7.5
Alkalinity	mg/L as $CaCO_3$	14-16
Hardness	mg/L as $CaCO_3$	8.6-21.6
Dissolved Oxygen	mg/L	9-13
TOC	mg/L	3.0-7.0
Turbidity	NTU	0.25-1.5

31

1   In the late 1980s, the District faced several source water quality issues. The TOC in the
2   Judy Reservoir supply ranged from 3 to 7 mg/L, leading to high formation of DBPs upon
3   chlorination. The District was having difficulty meeting CTs year-round, especially during the
4   colder months. The Judy Reservoir supply is soft and poorly buffered, with alkalinity levels
5   between 14-16 mg/L as $CaCO_3$, and the District exceeded the lead action level under the LCR.
6
7   **The Original Treatment Process at Judy Reservoir**
8
9   Before changes were made, initial oxidation/ disinfection was provided by chlorine
10 dioxide, primarily to oxidize manganese which is present in the 0.2-0.3 mg/L range. Coagulants
11 consisting of hybrid aluminum salts and a polyquaternaryamine were used. Direct filtration was
12 conducted with a slight addition of a mild anionic filter aid. The filter media consisted of one
13 foot of silica sand and two feet of anthracite coal.   Typical flows were 6000 gpm (8.6 mgd) in
14 the winter and 11,800 gpm (17 mgd) in the summer with 2000 square feet of available filter
15 surface area. Chloramination was used for secondary disinfection.
16
17 **Simultaneous Compliance Issues Faced by the Utility**
18
19   The District was having difficulty meeting CTs required by the SWTR. To address this
20 problem, free chlorine was historically applied ahead of the flocculation basins to increase CTs.
21 However, TOC levels in the Judy Reservoir led to high formation levels of DBPs upon
22 chlorination. This situation created difficulty for the District in complying with the Stage 1
23 D/DBPR. Exhibit B.2 shows the historical relationship between inactivation ratio (calculated CT
24 divided by required CT) and TTHM formation.
25

1
2   **Exhibit B.2 Inactivation Ratio vs. TTHM Plant Effluent**
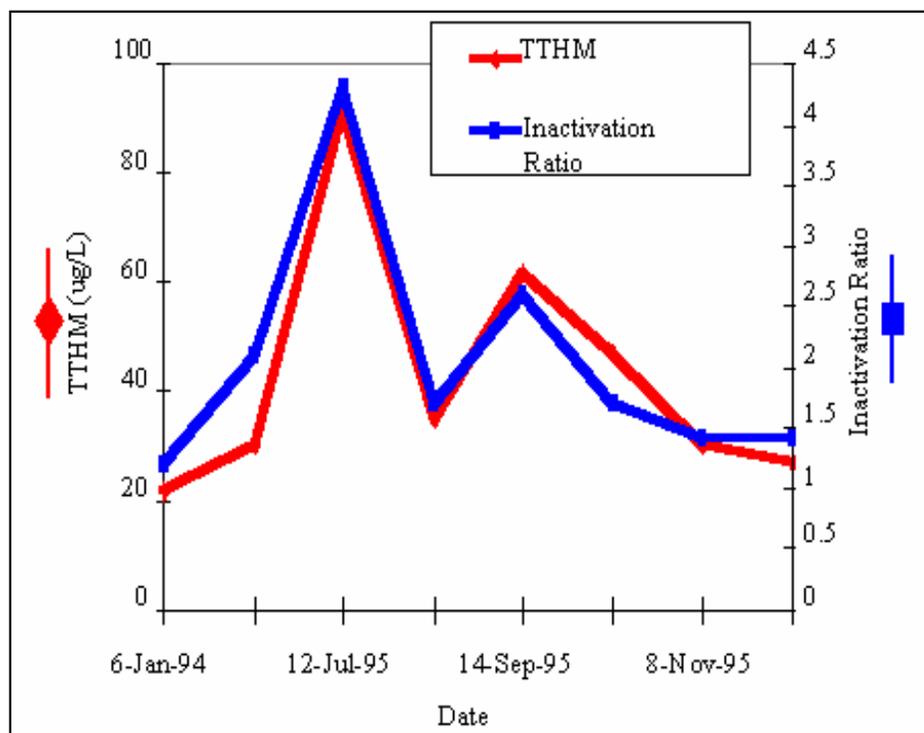
3
4   Using existing treatment methods, CTs could not be met consistently without
5   significantly increasing DBPs. Thus, a method other than increasing chlorine and contact time
6   was needed to achieve higher inactivation ratios. Methods of decreasing pH levels throughout
7   the treatment train were therefore considered. Because the District used direct filtration (rather
8   than conventional filtration), they were not required to meet TOC removal criteria under the
9   Stage 1 D/DBPR. However, lowering the pH at the beginning of the treatment train would have
10 the added benefit of enhancing coagulation, increasing the removal of DBP precursor materials.
11
12   Simultaneously, the District was having difficulty complying with the LCR; the 90th
13 percentile lead level was 0.049 mg/L at a finished water pH of approximately 7.3. The pH was
14 raised to 8.0 but the lead action level was still exceeded. Electrochemical corrosion testing was
15 conducted to compare the corrosion control effectiveness of pH adjustment and orthophosphate
16 addition for lead containing surfaces. The greatest reductions in corrosion rate were observed
17 when the pH was raised to 8.5, or when the pH was raised to 8.0 and 4 mg/L (as PO_4) were
18 added. Due to a number of functional constraints, the District did not want to add phosphates to
19 the water supply. Thus, the decision was made to increase pH to the range of 8.5 to 9.0.
20

1   Like most surface water supplies in the Pacific Northwest, the District's Judy Reservoir
2   supply is very soft and poorly buffered. Alkalinity levels are between 14-16 mg/L as $CaCO_3$.
3   To maintain the desired pH range of 8.5 to 9.0 throughout the distribution system, alkalinity
4   increases would also be required.
5
6   **Steps Taken by the Utility**
7
8   The District injected CO_2 prior to the flocculation basins in addition to at the end of the
9   treatment train where caustic soda is added. The advantages of adding carbon dioxide ahead of
10   the flocculation basins were three-fold:
11
12   1) The associated pH depression increased coagulation efficiency to remove DBP
13   precursors;
14   2) The associated pH depression increased CTs throughout the treatment plant, allowing
15   chlorine injection to be reduced; and
16   3) Subsequent pH increases using caustic soda provided finished water with increased
17   alkalinity levels and, increased buffering capacity.
18
19   The chemistry of CO_2 is well understood and is used extensively throughout the water
20   and wastewater industry. However, use of CO_2 for WTP process control in the Pacific
21   Northwest was fairly uncommon. The stoichiometry of CO_2 addition in the pH range of 6.0 to
22   10.0 is outlined below.
23
24              $$CO_2 + H_2O \longrightarrow H_2CO_3 \text{ (carbonic acid)}$$
25              $$H_2CO_3 \longrightarrow H^+ + HCO_3^- \text{ (bicarbonate)}$$
26
27   Over the pH range of 6.0-10.0, the dissociation of carbonic acid in water depresses the pH and
28   adds bicarbonate, which is the primary contributor to alkalinity.
29
30   CO_2 feed was set up at two locations within the District's treatment facility: 1) ahead of
31   the flocculation basins and 2) at the plant effluent. CO_2 injection began on a trial basis during
32   March, 1995. 24-144 lb/d (2 mg/L) were injected ahead of the flocculation basins (depending on
33   plant flow), and 192 lb/d (3 mg/L) were injected after filtration. The target pH level ahead of the
34   flocculation basin was less than 6.5. Additional CO_2 was required prior to caustic soda addition
35   to raise the alkalinity of the finished water to 25 mg/L as $CaCO_3$.
36
37   **Results of the Steps Taken**
38
39   *Effects on DBP Formation*
40
41   With the depression of pH and resulting increased coagulation efficiency, the percent of
42   TOC removal increased from an average of 25 percent to approximately 40 percent. The mass of
43   TOC removed nearly tripled from 1 mg/L to 2.5-3 mg/L. The percent and mass of TOC

1   removed before and after CO_2 injection are shown in Exhibit B.3. Thus, even a small decrease in
2   pH (from 6.9 to 6.6) during coagulation and flocculation has significantly enhanced coagulation.
3
4   Exhibit B.3 shows the percent and max of TOC removed after CO2 injection was
5   initiated in March 1995. During the first few months, CO2 was fed on a trial basis using a
6   temporary feed system that restricted the amount of CO2 that could be added. Thus, initial
7   decreases in TOC removal were observed until the system stabilized.
8
9   TTHM formation within the treatment train was reduced by approximately 33 percent.
10   Observed decreases in TTHM formation can be attributed to enhanced TOC removal, reduced
11   chlorine levels, and to the fact that less TTHMs are formed at lower pH levels. Prior to CO_2
12   addition, HAA5 levels in the plant effluent ranged between 40-60 µg/L when TOC levels were
13   between 3-5 mg/L. After CO_2 addition, HAA5 levels in the plant effluent decreased to the range
14   of 35-45 µg/L even though raw water TOC levels were in the range of 5-7 mg/L.
15
16
17   **Exhibit B.3 TOC Removal vs. Time**
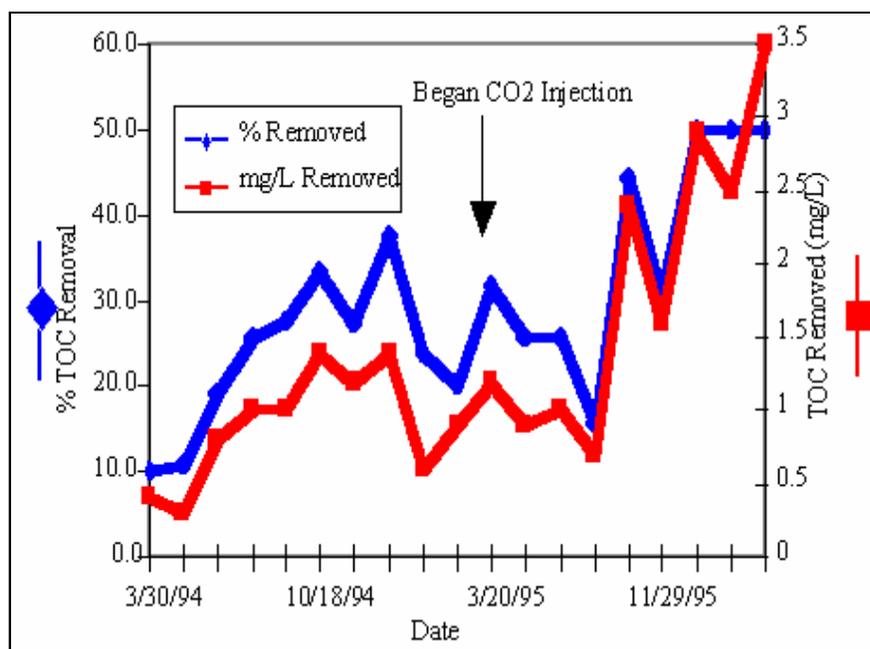
18
19   *Effects on CT Compliance*
20
21   CT credit decreases as temperature, disinfectant concentration, and contact time decrease.
22   CT credit using chlorine increases as pH decreases. Since DBP formation was a concern for the

1 District, the best way to increase CT credit without forming additional DBPs was to lower the
2 pH.
3
4   It is difficult to show actual improvements in the District's CT compliance as a result of
5 CO_2 addition since disinfectant dosages, plant throughput (i.e., contact time) and temperature
6 vary from month to month. However, the impacts of depressing the pH by 0.5 units are outlined
7 in terms of required chlorine dose and required contact time in Exhibit B.4.
8
9
10   **Exhibit B.4 Impacts of CO_2 Injection on CTs**
11

Effect of pH on Required Free Chlorine Dosages		
pH	**Contact Time (min)**	**Required Free Cl_2 (mg/L)**
7.0	82.5	2.0
6.5	82.5	1.67
6.0	82.5	1.41
Effect of pH on Required Contact Time		
pH	**Contact Time (min)**	**Required Free Cl_2 (mg/L)**
7.0	82.5	2.0
6.5	69	2.0
6.0	58	2.0

12
13
14   Thus, the same CT can be achieved with less chlorine. Alternatively, higher flows can be
15 accommodated without increasing chlorine dosages. It should be noted that in addition to
16 considering impacts of reduced chlorine dosages on CT, utilities must consider other drivers for
17 determining chlorine dose, such as the ability to maintain a disinfectant residual throughout the
18 distribution system. Because Skagit PUD#1 chloraminates, they are able to maintain a stable
19 residual despite fluctuations in chlorine dosage at the head of the treatment plant.
20
21 *Effects on Corrosion Control Treatment*
22
23   Distribution system water quality sampling suggested that pH and alkalinity levels are
24 more uniform throughout the system. Alkalinity levels have nearly doubled (from 14 mg/L as
25 $CaCO_3$ to 25 mg/L as $CaCO_3$), resulting in more stable water with respect to pH and corrosion
26 control. Prior to CO_2 injection, the District would raise the pH of the finished water to 8.0, but it
27 would decrease to 7.4 at many locations within the distribution system. Follow-up LCR
28 monitoring conducted by utilities across the U.S. has shown that providing consistent and stable
29 pH/ alkalinity levels can be essential to controlling lead levels at the tap. The District found that
30 nearly a year of CO_2 injection has to pass before pH levels stabilized within the distribution
31 system.
32

1   Lead levels at the tap decreased substantially at most of the "high lead" homes in the
2   District. The 90th percentile lead level was 0.004 mg/L during the last round of monitoring
3   conducted in 2003. It is likely that increased alkalinity helped to decrease lead levels by two
4   different mechanisms: 1) providing stabilized pH levels at the tap; and 2) increasing carbonate
5   levels to aid in the formation of more stable lead carbonate passivating films.
6
7   A study was undertaken by the District to determine whether elevated lead levels
8   measured at the tap were in the soluble or particulate form. It was found the lead was primarily
9   in the particulate form. When the pH was adjusted to 8.0 without alkalinity adjustment, elevated
10   lead levels were mostly due to particulate lead (particulate being the difference between total and
11   soluble lead), suggesting that stable lead carbonate films were not forming. After the pH was
12   further increased and the alkalinity was doubled, total lead concentrations decreased as shown
13   for three sampling locations in Exhibit B.5. Although lead solubility theoretically decreases as
14   pH increases to a maximum of 9.5, alkalinity adjustment may also be necessary to address the
15   particulate lead fraction.
16
17
18   **Exhibit B.5 Total vs. Soluble Lead**

Legend:
- Total Lead - pH 8.0 - Dec 93
- Total Lead - pH 9.0 - Apr 96
- Soluble Lead - pH 9.0 - Apr 96

Lead Action Level = 0.015 mg/L

Y-axis: Lead (mg/L)
X-axis: Sample Location (62, 63, 64)

1   **Implementation and Operational Issues Faced by the Utility**
2
3   CO_2 does not solubilize instantaneously, and therefore a pressurized solution feed system
4   was required. In this system, the CO_2 is injected to a pressurized side stream forming carbonic
5   acid. The carbonic acid solution is readily solubilized by the receiving water and is injected
6   directly into the pipeline.
7
8   Chemical costs for caustic soda doubled once CO_2 was injected since twice as much
9   caustic was required to raise the pH to 8.5-9.0. Considering the multiple benefits the District is
10   experiencing, a chemical cost increase of $30,000 per year or $10 per million gallons treated was
11   relatively inexpensive. The capital cost of the permanent CO_2 system was $15,000 (1996
12   dollars).
13
14   **Lessons Learned From this Case Study**
15
16   •   It is possible to achieving both greater Ct and TOC removal by reducing pH during
17   treatment.
18   •   pH reduction can in some cases be achieved through CO_2 injection.
19   • CO_2 injection at multiple locations during treatment may enhance benefits compared to
20   injection at the end of treatment only for pH control purposes.

1
2
3
4
5

Case Study #3
Presedimentation
Kansas City Water Services
Kansas City, Missouri

6   This case study provides an example of how Kansas City's existing pre-sedimentation basins
7   may help to achieve compliance with the upcoming regulations.
8
9   Kansas City's presedimentation basins were constructed prior to development of the
10 DBPRs and ESWTRs, but still provided a benefit with respect to regulatory compliance. These
11 pre-sedimentation basins have the potential to assist in providing the following benefits:
12
13   ✓ TOC reduction required under the Stage 1 D/DBPR due to coagulation in the basins;
14   ✓ Turbidity reduction necessary for compliance with the ESWTR; and
15   ✓ Lower *Cryptosporidium* levels for purposes of bin classification.
16
17   Systems with presedimentation in place at the time they begin LT2ESWTR
18 Cryptosporidium monitoring are not eligible for the 0.5 log presumptive credit and must sample
19 after the basin when in use for the purpose of determining their bin classification for
20 LT2ESWTR. Because Kansas City's pre-sedimentation basins were built decades before
21 promulgation of the LT2ESWTR, Kansas City cannot receive a credit for *Cryptosporidium*
22 removal for the basins under the LT2ESWTR. However, this may result in a lower bin
23 classification due to reduced particle concentrations in the basin effluent.
24
25   Simultaneous compliance issues associated with presedimentation basins may also
26 include the potential for algae blooms, which can increase disinfection by-product formation at
27 the plant effluent. Additionally, simultaneous compliance with the provisions of the
28 LT2ESWTR and the Stage 1D/ DBPR necessitates designating two different existing locations as
29 the treatment plant point of entry. For LT2ESWTR bin classification, the treatment plant point
30 of entry is considered to be the effluent of the pre-sedimentation basins. For the Stage 1
31 D/DBPR, the treatment plant point of entry is the influent to the pre-sedimentation basins.
32
33   This case study was developed using information available from staff at Kansas City
34 Water Services.
35
36 **Introduction**
37
38   The Kansas City, Missouri drinking WTP, which was originally constructed in the 1920s,
39 is rated for 240 MGD. The source water comes from the Missouri River and wells under the
40 influence of the Missouri River. The treatment process involves pre-sedimentation, excess lime
41 softening, recarbonation, filtration, and stabilization.
42

1   Due to the turbidity levels of the Missouri River, the pre-sedimentation basins are a
2   critical step in the City's WTP processes. The turbidity of the untreated source water is quite
3   variable, averaging 114 nephelometric turbidity units (NTU) in 2002, 185 NTU in 2003, and 318
4   NTU in 2004. The untreated water turbidity can exceed 5,000 NTU. The turbidity of the
5   untreated source water was even higher and more variable when the plant was built. However,
6   the construction of several upstream dams during the 1960's resulted in lower turbidity levels at
7   the City's intake. In addition, the pre-sedimentation basins serve to reduce the amount of solids
8   entering the softening process.
9
10   The plant was constructed well before the Safe Drinking Water Act (SDWA) and
11 subsequent drinking water regulations came into effect. Therefore, the pre-sedimentation basins
12 were not designed to meet compliance issues as much as they were needed as part of the water
13 treatment process. However, as the treatment regulations evolved, the pre-sedimentation basins
14 helped the plant meet new regulations.
15
16 **The Treatment Process at the Kansas City, Missouri WTP**
17
18   Today there are 6 presedimentation basins, each with a detention time of about 4 hours at
19 40 MGD. Each pre-sedimentation basin is approximately 200 feet in diameter and has an 80-
20 foot diameter fiberglass ring installed that is approximately half the height of the basin. This
21 fiberglass ring serves as a mixing area for the coagulation chemicals to react. There are four
22 mixers in each pre-sedimentation basin. These mixers and the capability for chemical injection
23 were added to the pre-sedimentation basins in the 1970s. Lower source water turbidity levels
24 resulted in reduced solids loading to the pre-sedimentation basins and increased colloidal
25 materials, impacting the efficiency of the pre-sedimentation basins for removing turbidity.
26 Therefore, the mixing areas and chemical feed capabilities were added. However, the solids
27 removal capacity of the basins remained the same.
28
29 *Role of Presedimentation Basins in Regulatory Compliance*
30
31   Kansas City's presedimentation basins could be used to lower turbidity as part of
32 compliance with the Surface Water Treatment Rules (SWTRs). Additionally, compliance with
33 the Stage 1 D/DBPR requires removal of TOC from source water to reduce the formation of
34 DBPs. Presedimentation basins may serve to remove a portion of the TOC. Finally, although
35 Kansas City can not receive a 0.5-log *Cryptosporidium* reduction credit for the pre-existing
36 presedimentation basins, the basins may assist in removing *Cryptosporidium* from the source
37 water. Kansas City is required to monitor the effluent from their presedimentation basins to
38 determine their *Cryptosporidium* bin classification. Since presedimentation basin effluent levels
39 are lower than source water *Cryptosporidium* levels, this will likely result in a lower bin
40 classification, thereby reducing Kansas City's treatment requirements.
41

Simultaneous Compliance Issues Faced by the Utility and Steps Taken

Algae may grow in the presedimentation basins, which could contribute additional NOM and result in the formation of DBPs, affecting compliance with the DBP Rules. Kansas City has managed to avoid this simultaneous compliance issue by minimizing algae blooms through potassium permanganate addition in the presedimentation basins. Additionally, the velocity of the water in the presedimentation basins is kept high by the mixers. In the rare instance that algae is observed, it is minimal and typically resides around the sides of the presedimentation basins. Additionally, the presedimentation basins are followed by an excess lime softening step, during which pH levels are raised above 10 units, reducing the potential for algae growth in this step.

Kansas City must also now designate two different existing locations as treatment plant entry points for regulatory compliance monitoring. For compliance with the Stage 1 D/DBPR TOC removal requirements, Kansas City monitors the influent to their pre-sedimentation basins for the purposes of comparing source water TOC with TOC removed during treatment. However, for compliance with the LT2ESWTR, Kansas City must conduct source water monitoring at the effluent from the pre-sedimentation basins (USEPA 2003g).

Implementation and Operational Issues Faced by the Utility

The presedimentation basin improvements allow the plant to add a variety of treatment chemicals to control turbidity of the pre-sedimentation basin effluent. The water plant has the capability of feeding ferric sulfate, polymer, and potassium permanganate to these basins. The turbidity of the pre-sedimentation basin effluent is controlled based on the economics of the treatment plant operations. By adding different coagulation chemical concentrations and combinations, the turbidity exiting the pre-sedimentation basis can be reduced to below 10 NTU. The plant uses factors such as lime dose requirements to determine the optimal treatment in the pre-sedimentation basins. This is because higher turbidity water entering the softening basins usually has more colloidal material, which in turn requires more lime to provide the desired softening because of the competing reactions between the charges stabilizing the colloids and the calcium carbonate precipitation process. Thus, the cost of the coagulant dosage to obtain a certain turbidity from the basins is compared to the cost of the lime required to provide the desired softening and an economic balance is found.

The plant reports that 80-90 percent of the time, potassium permanganate is sufficient for addressing operational issues such as taste and odor control and turbidity control. The remainder of the time, ferric sulfate is able to maintain the plant's operation.

Lessons Learned From this Case Study

The following lessons were learned from Kansas City's experience with presedimentation basins:

1
2   • The pre-sedimentation basins reduce the effects of large and variable turbidity
3   episodes.
4
5   • Improving the pre-sedimentation basins to incorporate chemical treatment and mixing
6   allowed the presedimentation basins to become more useful in water treatment
7   operations by allowing the plant to control turbidity entering the softening basins as
8   well as assisting in removing TOC and DBP precursors.
9
10   • The potential drawbacks of pre-sedimentation basins such as increased NOM from
11   algae are minimized through operations.
12
13   • Utilities with existing presedimentation basins will need to designate a different
14   location as the treatment plant point of entry if they want to realize any benefit of the
15   pre-sedimentation basins with regard to *Cryptosporidium* removal. This location will
16   be different from the point of entry already used for compliance with other
17   regulations.

1
2
3
4
Case Study #4
Switching Coagulants
Hillsborough River Water Treatment Plant
Tampa, Florida

5
6 This case study describes how a system could simultaneously comply with the TOC removal
7 requirements of the Stage 1 D/DBPR and the turbidity removal requirements of the IESWTR.
8 Enhanced coagulation is a best available technology (BAT) for TTHM precursor removal for the
9 Stage 1 D/DBPR. This case study shows how a system implementing enhanced coagulation for
10 the Stage 1 D/DBPR simultaneously complied with requirements of the Stage 2 DBPR.
11
12 **Introduction**
13
14   The City of Tampa, Florida, operates a 100 MGD conventional treatment plant (the
15 Hillsborough River Water Treatment Plant, HRWTP). The HRWTP uses the Hillsborough River
16 as its source water. The plant, built in 1924, currently serves over 450,000 people. In 1991, it
17 switched from enhanced coagulation with alum to enhanced coagulation with ferric sulfate. The
18 influent surface water has high TOC and is subject to large seasonal variations. By switching
19 coagulant, the HRWTP's operators expected to satisfy requirements of the Stage 1 D/DBPR.
20 They had investigated the feasibility of enhanced coagulation with ferric sulfate before the Stage
21 1 D/DBPR became a regulatory requirement. They found that enhanced coagulation with ferric
22 sulfate not only increased TOC removal significantly, but also reduced turbidity levels in the
23 finished water.
24
25   A summary of the influent water quality is provided in Exhibit B.6.
26

1
2
Exhibit B.6 Influent Water Quality at HRWTP

Water Quality Parameters	Influent[1]
TOC (mg/L) Minimum Average Maximum	4.3 13 26
Turbidity (NTU) Minimum Average Maximum	1.2 2.1 40
pH Minimum Average Maximum	6.8 7.6 8.5
Alkalinity (mg/L as CaCO$_3$) Minimum Average Maximum	42 93 143

3   Notes: 1. Data from an Information Collection Rule (ICR) sample collection from July 1997 -
4   December 1998
5
6
7   **The Original Treatment Process at HRWTP**
8
9   Exhibit B.7 shows a schematic of the treatment process at HRWTP prior to converting to
10   ferric sulfate. Raw water was treated with potassium permanganate for taste and odor control.
11   Enhanced coagulation was implemented using alum (range of alum dose = 50 - 200 mg/L,
12   average dose = 120 mg/L), at an average pH of 5.7 (range 4.9 - 6.6). An organic polymer was
13   added to enhance the flocculation process. Primary disinfection was attained by applying
14   chlorine just prior to the filters. After filtration, more chlorine and ammonia were added to form
15   chloramines for residual disinfection. The pH of the finished water was increased to around 7.6
16   with caustic soda and soda ash in the blending chamber, to meet a Langelier Index goal of +/-0.2.
17
18

1
2   **Exhibit B.7 Treatment at the HRWTP Prior to Implementing Enhanced Coagulation**
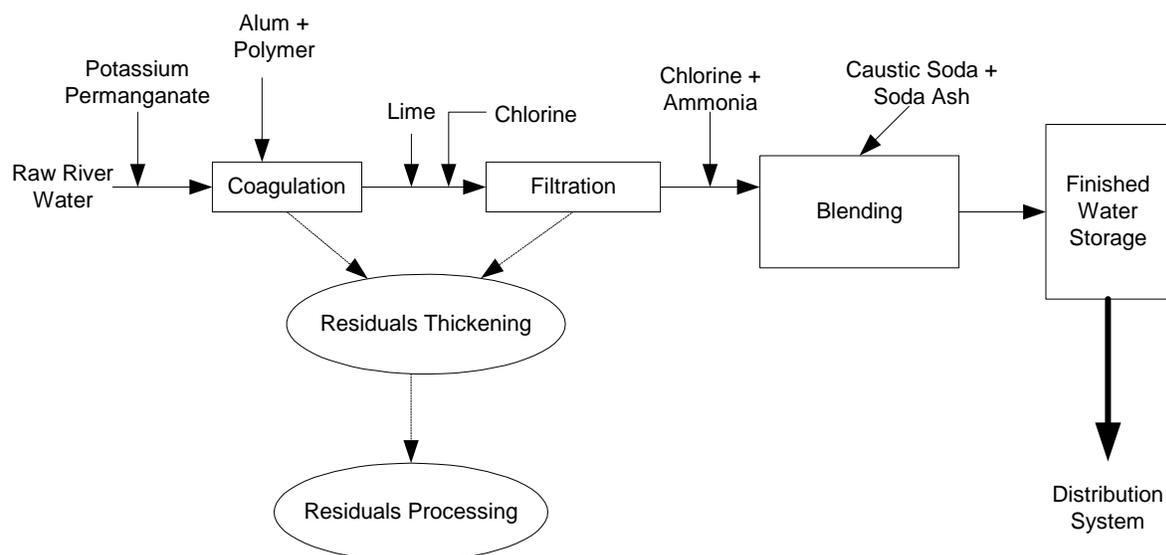
3
4
5   **Simultaneous Compliance Issues Faced by the Utility**

6
7   In order to reduce DBP precursors and TTHM and HAA5 concentrations, the City of
8   Tampa decided to switch to enhanced coagulation with ferric sulfate, enhancing TOC removal
9   and consequently lowering the DBP formation potential.

10
11   Successfully enhancing coagulation to improve TOC removal can affect particle and
12   pathogen removal effectiveness. The system was concerned that, at lower pH, the higher
13   coagulant dose conditions for enhanced coagulation could result in particle re-stabilization and
14   an increase in settled water turbidity, leading to non-compliance with the IESWTR. Increased
15   settled water turbidity could also impact the system's ability to receive *Cryptosporidium* removal
16   credit for enhanced filter performance. Variability in source water quality presented a further
17   challenge to the operators who were attempting to optimize particle and TOC removal with a
18   new coagulant.

19
20   **Steps Taken by the Utility**

21
22   Tampa implemented enhanced coagulation with ferric sulfate to improve TOC removal.
23   At the same time, it applied BMPs to ensure that filter effluent turbidity would not be adversely
24   affected. These included flow-pacing the coagulant feed and conducting additional jar tests to
25   ensure that coagulant overdosing did not occur.

1
2   Exhibit B.8 shows a schematic of the treatment process at HRWTP after the system
3   changed to enhanced coagulation with ferric sulfate. Raw water continues to be treated with
4   potassium permanganate for taste and odor control. Enhanced coagulation uses ferric sulfate
5   (range dose = 40 - 300 mg/L, average dose = 140 mg/L), at an average pH of 4.0 (range 3.5 -
6   4.8). The low coagulation pH is attained by adding sulfuric acid. An organic polymer is added
7   to enhance the flocculation process. The settled water is treated with lime for partial pH
8   adjustment. The residuals are thickened and then pumped to a residuals processing facility for
9   further dewatering, processing, and disposal. Primary disinfection is attained by adding chlorine
10   to the settled water to produce a free residual of 1-2 mg/L just prior to the filters. After filtration,
11   ammonia and chlorine are added to form chloramines. The finished water combined disinfectant
12   residual ranges from 3 - 4.5 mg/L of monochloramine. The pH of the finished water is adjusted
13   to around 7.6 with caustic soda and soda ash in the blending chamber, to meet a Langelier Index
14   goal of +/-0.2.
15
16
17   **Exhibit B.8 Treatment at the HRWTP After Implementing Enhanced Coagulation**
18
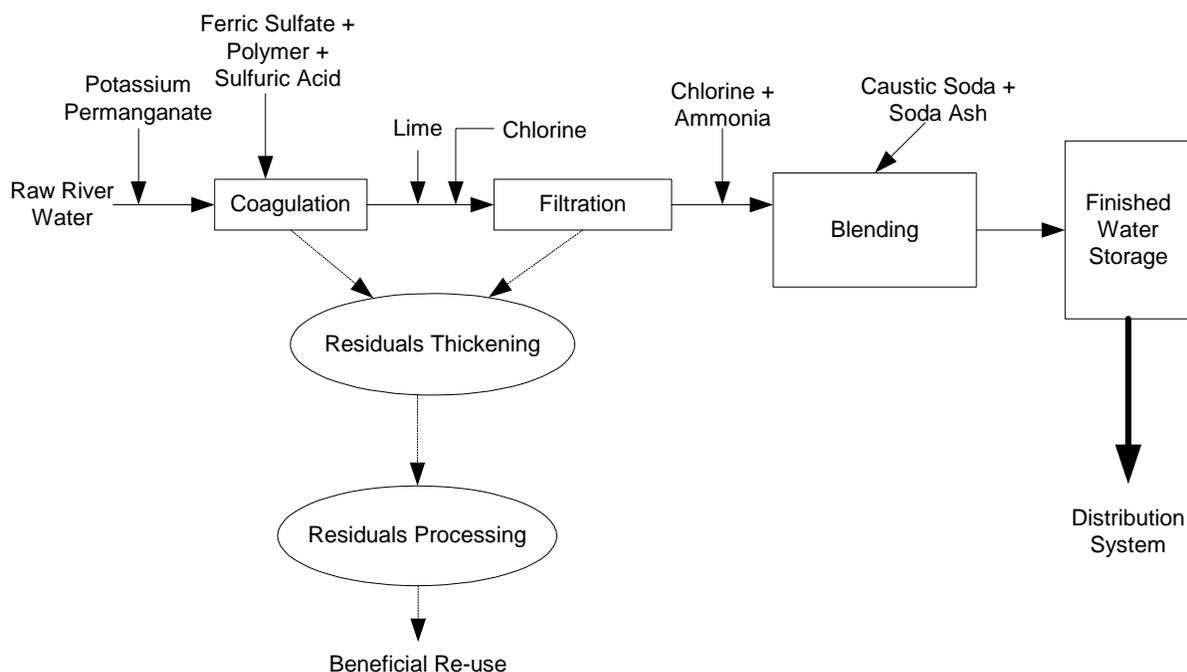
19
20   To ensure that excessive coagulant dosing doesn't occur, the operators check the
21   coagulant dose regularly with jar tests. The operators also ensure that coagulant feed is flow
22   paced. These practices help ensure that turbidity requirements are not violated.

1
2 **Results of the Steps Taken**
3
4   • TOC removal - Finished water TOC removal with enhanced alum coagulation ranged
5   from 21 to 50 percent. For enhanced coagulation with ferric sulfate, TOC removal
6   ranges from 70 to 88 percent, with an average of 81 percent. This is well beyond the
7   minimum TOC removal requirements of the Stage 1 D/DBPR (based on the source
8   water TOC and alkalinity concentrations). Influent and effluent water quality is
9   shown in Exhibit B.9. Thus, enhanced coagulation with ferric sulfate is much more
10   effective than enhanced coagulation with alum for removing DBP precursors.
11
12   • TTHM reduction - Before the changes in the coagulation practice, the finished water
13   TTHM ranged from 27 - 111 μg/L, with an average of 59 μg/L (Exhibit 4). After the
14   treatment modifications (from July 1997 through December 1998), the finished water
15   TTHM ranged from 47 - 67 μg/L, with an average of 60 μg/L. Enhanced coagulation
16   with ferric sulfate seems more effective than coagulation with alum at removing DBP
17   precursors (i.e., TOC), when the raw water is high in TOC. This is reflected by the
18   lower maximum level of TTHM measured after treatment modifications (i.e., the
19   maximum trihalomethane (THM) concentration was reduced from 111 to 67 μg/L).
20   The new treatment approach reduced THMs by increasing TOC removal and
21   chlorinating at a lower pH. Implementing enhanced coagulation with ferric sulfate
22   has enabled HRWTP to achieve compliance with the Stage 1 TTHM MCL of 80
23   μg/L.
24
25   • Turbidity - As can be seen clearly from Exhibit B.9, enhanced coagulation with ferric
26   sulfate was more effective than alum coagulation at reducing turbidity in the finished
27   water. Enhanced coagulation with ferric sulfate was able to achieve the IESWTR
28   turbidity requirements more easily and consistently.
29

1   **Exhibit B.9 Finished Water Quality Before and After Implementing Enhanced**
2   **Coagulation with Ferric Sulfate**
3

Water Quality Parameters	Influent[1]	Finished Water	
		Before implementing Enhanced Coagulation[2]	After implementing Enhanced Coagulation[3]
TOC (mg/L) Minimum Average Maximum	4.3 13 26	1.8 6.2 8.9	1.6 2.9 5.1
Turbidity (NTU) Minimum Average Maximum	1.2 2.1 40	0.04 0.32 1.13	0.04 0.11 0.28
pH Minimum Average Maximum	6.8 7.6 8.5	7.1 7.6 8.2	7.2 7.6 7.7
Alkalinity (mg/L as CaCO$_3$) Minimum Average Maximum	42 93 143	80 122 187	48 92 125
TTHM (μg/L) Minimum Average Maximum	NA	27 59 111	47 60 66
HAA5 (μg/L) Minimum Average Maximum	NA	NDC	32 47 66

4   Notes:
5   1. Data from ICR sample collection from July 1997 - December 1998
6   2. Data collected for calendar year 1990.
7   3. Data collected for calendar year 1997; ICR data from July 1997 - December 1998 was used for organic
8   analysis.
9   4. NDC = No Data Collected
10   5. NA = Not Applicable
11
12

1   **Implementation and Operational Issues Faced by the Utility**
2
3   • Operator training and start-up - It took around 6 months for the operational staff to
4   be comfortable with implementing enhanced coagulation, and nearly a year for the
5   treatment plant to operate like an integral unit. The treatment strategy did not
6   significantly change the operational needs of the plant and no additional staff were
7   added.
8
9   • Controlling manganese - The only major problem experienced in implementing the
10   treatment modification was the control of manganese. The lower pH required for
11   enhanced coagulation with ferric sulfate, relative to alum coagulation, allowed
12   dissolved manganese to pass through the filters. The issue was resolved by
13   maintaining the pH on top of the filters at greater than 6.0.
14
15   Corrosion due to acid addition - The addition of sulfuric acid promoted corrosion in the rapid-
16   mix chamber at the feed diffuser. The problem was resolved when the utility found a suitable
17   coating for their rapid-mix chamber. The coating used was a two-part commercial membrane
18   applied at 60 wet mils, using an air-supplied mastic air gun. After application, the coating
19   required a 7-day curing period before the basin could be put back into service. The settling
20   basins were epoxy-coated and did not experience any corrosion.
21
22   **Lessons Learned From this Case Study**
23
24   • Enhanced coagulation with ferric sulfate can achieve the multiple objectives of
25   increased TOC removal and improving reductions in finished water turbidity without
26   significantly changing the operational needs of the plant.
27
28   • One key to successfully implementing enhanced coagulation is to ensure that
29   excessive coagulant dosing does not occur. This results in turbidity breakthrough at
30   the filters, resulting in potential non-compliance with the IESWTR. One way to
31   achieve this is by conducting additional jar tests and flow-pacing the coagulant feed
32   when plant water flows are variable.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

This page intentionally left blank.

1   **Case Study #5**
2   **Enhanced Coagulation - Problems with Copper Pitting**
3   **Washington Suburban Sanitary Commission**
4   **Montgomery and Prince Georges County, Maryland**
5
6
7   This case study provides an example of negative effects that could possibly be caused by
8   enhanced coagulation. Washington Suburban Sanitary Commission (WSSC) changed their
9   coagulation process to reduce filtered water turbidity. This was implemented prior to
10   development of the Stage 1 D/DBPR and, therefore, not optimized to meet associated
11   requirements. However, WSSC's experience indicates that coagulation improvements might
12   have had unintended results in the distribution system. After alterations were made to WSSC's
13   coagulation process, WSSC customers began reporting pinhole leaks in their copper piping,
14   possibly caused by a combination of factors. The utility has been unable to determine the exact
15   cause of the pinhole leaks. In this case study, the primary concerns relate to compliance with:
16
17   • LCR, and
18   • DBP Rules.
19
20   While this treatment was implemented prior to the DBP Rules, it does indicate a potential
21   problem associated with implementing the Stage 1 D/DBPR's required treatment technique using
22   enhanced coagulation.
23
24   This case study was developed using information available from staff at the WSSC and from
25   their customer care Web site detailing this issue
26   (http://www.wsscwater.com/cfdocs/ copperpipe/pinholescroll.cfm). The cause of pinhole leaks
27   in WSSC's system continues to be under investigation.
28
29   **Introduction**
30
31   The WSSC provides drinking water to 1.6 million people in suburban Maryland. WSSC
32   relies on two rivers, the Potomac and Patuxent, to supply an average of 167 MG per day. Both
33   river supplies are treated at separate filtration plants. The Potomac plant treats river supply while
34   the Patuxent plant treats water from a reservoir system. In the mid-1990s, WSSC made
35   treatment changes at the Potomac plant to enhance filtration performance, including changing
36   filtration media and changing coagulant, from ferric chloride to polyaluminum chloride. During
37   the 1990s, coagulant doses were increased slightly at the Patuxent plant, which used alum most
38   of the time, occasionally switching to ferric chloride during the winter.
39

1   The primary reasons WSSC made these treatment changes were:
2
3   • Prevention of waterborne pathogen outbreaks - A large-scale cryptosporidiosis
4   outbreak occurred in Milwaukee, Wisconsin in 1993. The outbreak coincided with
5   elevated effluent turbidity levels. Studies of the causes and prevention methods
6   indicated that coagulation and filtration performance are critical in preventing the
7   entry of *Cryptosporidium* to the distribution system.
8
9   • Partnership for Safe Water - This is an industry program, supported by EPA and the
10   American Water Works Association (AWWA), that focuses on protecting drinking
11   water customers from microbial contaminants. WSSC has participated in this
12   program that includes meeting stringent criteria for turbidity in filtered drinking
13   water.
14
15   While WSSC's coagulation changes were not optimized for compliance with the Stage 1
16 D/DBPR, WSSC did observe lower TOC levels in effluent at the Potomac WTP.
17
18 **The Original Treatment Process at WSSC's WTPs**
19
20   Both the Potomac and Patuxent Treatment Plants include similar treatment processes:
21
22   • Coagulation and flocculation
23   • Sedimentation
24   • Filtration
25   • Fluoridation
26   • Lime addition for corrosion control
27   • Chlorination
28
29 **Simultaneous Compliance Issues Faced by the Utility**
30
31   In 1998, WSSC began receiving complaints from customers that pinhole leaks were
32 developing in their copper piping. As of December 2004, almost 5,500 customers have reported
33 this problem. Pinhole leaks have occurred in areas served by both drinking water supply
34 sources. WSSC has collected data on pinhole leaks from customers and these trends have been
35 apparent:
36
37   • Many pinhole leaks are in cold water horizontal copper piping
38   • Many leaks are located in older portions of service area
39   • Almost 80 percent of leaks have occurred in homes built before 1970
40
41   In 2000, WSSC formed a task force to study the pinhole leaks and possible causes. The
42 task force included WSSC staff, copper and plumbing industry experts, and corrosion experts.

1   The researchers conducted bench-scale experiments with copper piping and simulated drinking
2   water and determined that a combination of high pH, aluminum solids, and chlorine levels, and
3   no remaining NOM caused significant pitting on copper piping in about one month (Marshall,
4   Rushing and Edwards 2003).
5
6   NOM present in drinking water supplies is a DBP precursor and is typically removed
7   through filtration or coagulation. TOC levels usually correspond to the presence of NOM in
8   drinking water. The presence of NOM in the distribution system was previously thought to
9   prevent, to some extent, corrosion of piping materials, such as cement, iron, and copper. The
10 research by Marshall, Rushing and Edwards (2003) contradicts previous understanding of
11 NOM's role in copper corrosion.
12
13 Water quality conditions in WSSC's distribution system that may have contributed to pinhole
14 leaks in copper piping include:
15
16   •   Aluminum - Since 1995, both treatment plants have used an aluminum-based
17   coagulant. Finished water aluminum levels are relatively low. The average Potomac
18   WTP residual levels range from 0.046 mg/L to 0.060 mg/L, and at Patuxent WTP,
19   which recently switched from alum to polyaluminum chloride, average effluent
20   aluminum levels are 0.030 mg/L (Edwards et al. 2004). In comparison, the national
21   average for effluent aluminum levels is 0.090 mg/L.   Sampling in WSSC's
22   distribution system indicated that aluminum levels increased after treatment to levels
23   higher than 0.065 mg/L total aluminum.   Researchers indicate that high aluminum
24   samples were collected in areas near recently cleaned or re-lined piping (Edwards et
25   al. 2004). A forensic analysis of WSSC failed copper piping showed that aluminum
26   deposits were frequently present (Marshall, Rushing and Edwards 2003).
27   •   Chlorine - WSSC, like the majority of utilities, uses chlorine to provide a disinfectant
28   residual in the distribution system.
29   •   pH - WSSC increases the pH of water entering their system during the treatment
30   process for corrosion control. Water from the Potomac WTP has a pH of about 7.5 in
31   the distribution system. Until recently, the Patuxent WTP had a pH of about 8.2 in
32   the distribution system (now adjusted to about 7.5 since orthophosphate addition
33   began).
34 TOC - The Potomac WTP achieves approximately 40 percent TOC removal, which is a slight
35 increase since the coagulant and filter media change. Patuxent reservoir water has a lower level
36 of NOM, with treated water TOC levels below 2 mg/L. TOC removal at the Patuxent WTP has
37 not changed.
38
39 **StepsTaken by the Utility**
40
41   In late 2003, WSSC implemented orthophosphate addition to both treatment plants.
42 Addition was phased in slowly with the dose reaching a level of 1 mg/L (as PO4) after 4 to 5

1 months. This gradual increase was recommended by WSSC's operations staff to limit the
2 potential for discolored water problems caused by phosphates forming comples with iron,
3 making it more soluble. In pilot-testing, orthophosphate effectively reduced pinhole leak
4 activity. WSSC participated in a state-wide task force that surveyed utilities regarding pinhole
5 leaks. WSSC also contacted the USEPA regarding the pinhole leak issue and research findings
6 that removal of NOM, as required in the DBP Rules, may promote pinhole leaks in certain
7 waters. Finally, WSSC has worked to educate the public on this topic.
8
9 **Results of the Steps Taken**
10
11   Overall, the utility is receiving fewer pinhole leak reports from their customers and area
12 plumbers have indicated that they are seeing fewer pinhole leaks. It will take more time before
13 WSSC can conclusively determine whether orthophosphate has addressed the problem.
14
15 **Implementation and Operational Issues Faced by the Utility**
16
17   WSSC experienced the following issues when implementing orthophosphate addition:
18
19 • Increased wastewater phosphorus resulted in increasing cost for wastewater
20   treatment.
21 • WSSC investigated the potential for orthophosphate addition to increase discolored
22   water complaints due to iron release from unlined cast iron mains.
23 • During summer conditions, turbidity of finished water (i.e., following post-filter lime
24   addition) has increased occasionally after orthophosphate addition. WSSC is still
25   investigating the cause.
26
27 **Lessons Learned From this Case Study**
28
29 • Switching coagulant may have unintended consequences on water quality.
30
31 • The role of NOM in copper corrosion control needs to be better understood by the
32   drinking water industry.
33
34 • The synergistic effects of chlorine and aluminum at pHs that have been optimized for
35   corrosion control also need to be better understood by the drinking water industry.
36   These interactions can be exacerbated for utilities that use free chlorine.
37
38 • Pilot-scale and/or electro-chemical testing for determining the impacts of chemicals
39   on corrosion control were useful in identifying an appropriate solution.
40
41 **References**
42

1   Edwards, M., J.C. Rushing, S. Kvech, and S. Reiber. 2004. Assessing copper pinhole
2   leaks in residential plumbing. *Water Science and Technology*. 49(2): 83-90.
3
4   Marshall, B., J. Rushing, and M. Edwards. 2003. Confirming the role of aluminum solids
5   and chlorine in copper pitting corrosion. In *Proceedings of AWWA Annual Conference*.
6   Denver CO.
7
8   Rushing, J.C. and M. Edwards. 2002. Effect of aluminum solids and chlorine on cold
9   water pitting of copper. In *Proceedings of AWWA Water Quality Technology Conference*.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

This page intentionally left blank.

1   <div align="center">**Case Study #6**</div>
2   <div align="center">**Enhanced Coagulation - Managing Radioactive Residuals**</div>
3   <div align="center">**Allen Water Filtration Plant**</div>
4   <div align="center">**Englewood, CO**</div>
5
6   This case study presents a discussion of a system's options for disposing of
7   radioactive residuals resulting from enhanced coagulation. Enhanced coagulation is
8   practiced at the system to meet the requirements of the Stage 1 D/DBPR. Uranium is
9   naturally occurring in the City's source water, but radionuclide levels in the raw water do
10   not warrant treatment for removal. The radionuclides become concentrated in the residuals
11   as a result of the enhanced coagulation process at levels that require special considerations
12   for regulatory approval of sludge disposal.
13
14   **Introduction**
15
16   The City of Englewood Allen WFP is a conventional treatment plant with an average
17   treated flow of 8.5 mgd (design flow of 28 mgd) to serve a population of 48,000 people. The
18   primary raw water supply comes from surface sources, including the South Platte River, Bear
19   Creek, and water sources diverted from the Western Slope of Colorado. The plant treatment
20   processes include addition of potassium permanganate, coagulant, and coagulant aid to the
21   pipeline ahead of the rapid mix. Mixing is followed by three-stage tapered flocculation and
22   settling using lamella inclined plates. The water passes through GAC filters prior to chlorine
23   addition. Chlorine contact time is obtained in the clearwell and ammonia is added after the
24   clearwell for chloramine disinfectant residual in the distribution system. Sedimentation sludge
25   and filter backwash water are dewatered by belt press and the filtrate is sent to the backwash
26   settling lagoon along with the waste backwash water. Decant from the backwash settling lagoon
27   is returned to the North Reservoir to be recycled to the head of the plant. Recycle goes into the
28   washwater lagoon (aka backwash settling lagoon) which overflows to an 80 million gallon
29   reservoir that is used sparingly as source water as it is blended with raw water drawn from other
30   sources. The approximate recycle return flow is 1.5%. Treatment includes settling of solids in
31   the lagoon and in the reservoir.
32
33   Exhibit B.10 presents source water and finished water quality details. A process
34   schematic is shown in Exhibit B.11.
35

1

2 **Exhibit B.10 Typical Water Quality Parameters at Allen WFP**

3

Water Quality Parameter	Raw Water	Treated Water
Turbidity (NTU)	1.0 - 12	0.10 - 0.24
pH (SU)	7.9 - 8.7	7.6 - 8.4
TOC (mg/L)	3.5 - 5.0	2.6 - 3.75
Alkalinity (mg/L as CaCO3)	55 - 170	55 – 150
Barium (mg/L)	*	0.048
Selenium (ug/L)	*	0.0077
Alpha Emitters (pCi/L)	34 + 5	7.8 + 3.3
Beta/Photon Emitters (pCi/L)	*	10 + 5
TTHM (ug/L)	*	34 – 55
HAA5s (ug/L)	*	3 – 21

4   * If available, levels present in raw water will be added to next draft.

5

6

7   The Allen WFP practices enhanced coagulation to comply with the Stage 1
8 D/DBPR by the addition of alum with typical doses of 40 - 60 mg/L of alum. Based on the
9 average plant flow, the production rate of residuals would be expected to be 1632 lb/day or
10 302 cy/yr. Recently (2002-2004), residuals production from the backwash pond is
11 approximately 1600 cy/yr. The current large volume may be a result of catching up on
12 previous years' storage. City employees are processing residuals from March to November
13 to make sure the backwash pond does not exceed its capacity.

14

15

1   **Exhibit B.11 Allen Water Filtration Plant Schematic**
2
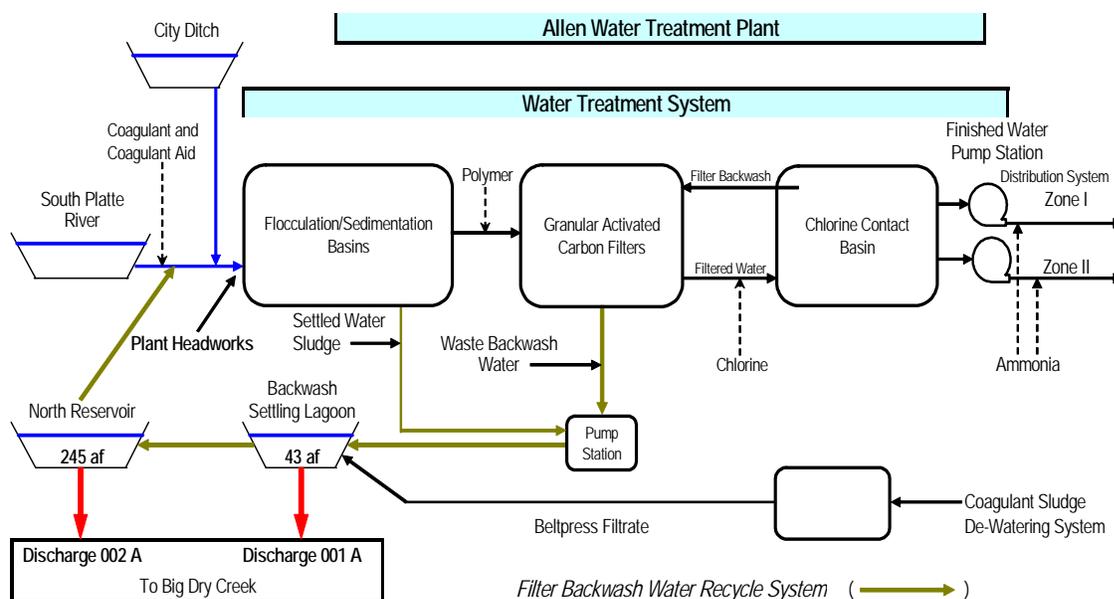
3
4
5   *Residuals Management Prior to Enhanced Coagulation*
6
7   The City of Englewood has historically disposed of water treatment residuals by
8   land applying dried residuals at the City golf course. These residuals were mixed with fill
9   dirt (2:1 ratio fill to residuals) for berm construction with grass cover. This procedure met
10   the requirements of the Colorado Department of Health and Environment (CDPHE) with
11   respect to the state's solid waste regulations and the hazardous/radioactive material
12   regulations. Residuals disposal facilities in Colorado must comply with all Colorado
13   health laws and with CDPHE regulations and standards. Acceptance criteria for solid
14   waste disposal include:
15
16   • WFP residuals containing any free liquid cannot be accepted for disposal
17   • WFP residuals with a pH less than 6.0 cannot be accepted for disposal
18   • WFP residuals with a total alpha activity value exceeding 40 pCi/g of dry solids
19   require additional CDPHE guidance prior to disposal. The residuals generator
20   must contact the CDPHE's Radiation Control Division and the Solid Waste
21   Division for guidance
22
23   Colorado drinking water utilities with residuals that have total alpha activity values
24   exceeding 40 pCi/g have disposed of residuals using landfill disposal, sanitary sewer
25   discharge, monofill disposal, and compost amendment with and without approval from
26   CDPHE.
27

1   Liquid residuals discharged to sanitary sewers are not regulated for water treatment
2 residuals disposal by CDPHE. Acceptance of water treatment residuals is approved by the
3 sanitary district authority based on impacts to the treatment process from additional flow
4 and solids loading.
5
6 **Simultaneous Compliance Issue Faced by the Utility**
7
8   Since the inception of enhanced coagulation at the Allen WFP, analysis of the
9 residuals has shown that the total alpha activity exceeds 40 pCi/g, resulting in the
10 requirement that the City of Englewood must notify CDPHE of disposal plans for the
11 residuals to comply with state regulations. The City can no longer dispose of residuals as
12 has been done in the past because CDPHE no longer allows land application at the golf
13 course. The concentrated residuals are considered technologically enhanced naturally
14 occurring radioactive materials (TENORM). Regulation of TENORM in drinking water
15 residuals is not clearly spelled out in Federal or state regulations.
16
17 **Steps Taken by the Utility**
18
19   The City undertook a study to develop a long-term residuals disposal plan. Six
20 disposal alternatives were evaluated using three criteria: compliance with residuals
21 disposal regulations, cost of disposal, and ease of implementation. The six alternatives
22 considered were as follows:
23
24 • *Discharge to the sanitary sewer* is not regulated by the state, however the waste
25   water treatment plant (WWTP) has a limit of 30 pCi/g for biosolids. Because
26   liquid residuals samples from the Allen WFP holding pond have an average
27   gross alpha level of 5,880 pCi/L, the allowable discharge rate would be limited
28   to a total flow well below the average daily production rate. This option is
29   therefore not operationally sound.
30 • *Disposal at an approved landfill* requires loading and trucking residuals to one
31   of two landfills at a distances of 44 miles or 100 miles from the plant site. The
32   landfills are approved for disposal of Resource Conservation and Recovery Act
33   (RCRA) wastes by the State of Colorado and all material disposed is
34   manifested and final disposal location within the landfill is documented. The
35   minimum operating cost of this option is $66,000 per year.
36 • *Compost/topsoil amendment recycling* requires the City to take responsibility
37   for loading dry residuals onto City trucks to transport to the facility. The
38   compost facility can mix residuals immediately upon delivery to avoid
39   stockpiling of residuals only material. The expected annual operating cost for
40   this option is $19,900.
41 • *Disposal at a new City monofill* requires the development, operation, and
42   eventual closing of a landfill operation used solely for Allen WFP residuals. In

1   addition, trucking of the residuals to the landfill site would be required. This
2   option requires a capital investment of approximately $1.4 million and annual
3   operating costs of $233,000.
4   • *On-site mixing with fill material* provides material ready for compost or topsoil
5   application. A portion of residuals is mixed with fill material with low
6   background gross alpha levels. City monitoring for gross alpha will be required
7   to ensure levels below 40 pCi/g. Expected annual operating cost for this option
8   is $68,100.
9   • *Disposal at out-of-state approved landfill* assumes transport of residuals by
10   truck or rail cars to the nearest landfill (600 miles away) that accepts TENORM
11   waste similar to the Allen WFP residuals. Material at this facility is manifested
12   and final disposal location in the landfill is documented. The expected annual
13   operational cost is a minimum of $202,500.
14
15   In addition to evaluating these six options, the City contracted for a human health
16   risk assessment to be done to determine possible radiation exposure to City and landfill
17   employees from managing the residuals, as well as the public exposure arising from
18   possible future property uses. The risk assessment utilized RESRAD Version 6.21
19   modeling software to assess the dose to workers and residents from contact with
20   radioactive material in the treatment plant residuals, either directly or indirectly. Included
21   were the possible radiation exposures for a landfill worker, a composting facility worker,
22   and a hypothetical future resident farmer living and farming the area above a closed
23   landfill. The risk assessment indicated that neither the landfill or compost worker would
24   be subject to significant radiation exposure resulting from the residuals handling. In
25   addition, the hypothetical future farmer is unlikely to experience exposures above typical
26   background levels in Colorado. Thus, the risk assessment supported the disposal of
27   residuals in a local landfill and at the compost recycling facility.
28
29   As of March 2006, the sludge is being disposed of at a licensed industrial landfill
30   within the state.
31
32   The City is assessing coagulation schemes that use less alum and produce less
33   residuals. One such possibility is using a 15 mg/L dose of polyaluminum chloride (PACl)
34   with a small supplemental dose of 8 mg/L of alum. Essential to making this change will
35   be the ability to remove sufficient TOC to meet the Stage 1 D/DBPR.
36
37   Since there is currently no state or Federal guidance for disposal of radioactive
38   water treatment residuals, the City has undertaken an effort with other local utilities to
39   assist the State CDPHE in development of guidance for the disposal of TENORM in
40   drinking water residuals.
41

Results of the Steps Taken

The long-term recommendation to the City is that residuals be transported to the compost/topsoil amendment recycling center. In addition the City is expected to obtain approval for both onsite mixing and in-state landfill disposal. Approval for all three disposal methods has been requested from CDPHE.

The State CDPHE has begun a stakeholder process that will ultimately result in guidance for utilities in disposing of TENORM.

Implementation and Operational Issues Faced by the Utility

The fact that appropriate Federal and state guidance does not yet exist to provide utilities with an understanding of requirements has made managing residuals much more complex. Approval from CDPHE must be obtained as soon as possible as residuals are currently stockpiled on the plant site at near capacity. If residuals handling operations are impacted with respect to volume, the drinking water treatment process may also be impacted with respect to production.

Lessons Learned From this Case Study

- The levels of radioactivity in sludge may be significantly higher than expected based on the background levels in the raw water when the treatment process produces residuals that concentrate contaminants. These residuals can be liquid and/or solid.

- Disposal to the sanitary sewer is likely to be a problem for almost any concentrated contaminant that is regulated in biosolids.

- No regulatory guidance is available to utilities to assist in developing disposal options for residuals that qualify as TENORM.

State regulatory agency groups that have responsibility for radioactive waste products are generally different from the group responsible for drinking water compliance. This can result in some complex interactions with regulators as the utility may find themselves in the role of initiating internal interactions within state agencies. In Colorado, the Hazardous Materials and Waste Management Division is the licensing group for disposal at hazardous waste disposal facilities or licensed radioactive waste facilities. Discharge permits, if the liquid waste meets water quality standards, are issued by the Water Quality Control Division's Colorado Discharge Permit System. Drinking water is regulated through the Water Quality Control Division Drinking Water Program.

1   **Case Study #7**
2   **Granular Activated Carbon Filtration for TOC Removal**[1]
3   **Higginsville Water Treatment Plant**
4   **Higginsville, Missouri**
5
6
7   **Introduction**
8
9   This case study provides an example of how a utility used GAC to address high
10   levels of atrazine in its source water and high TTHM levels in its finished water. Most of
11   the information for this case study came from Leung and Segar (2000). Interested readers
12   are referred to that reference for more information.
13
14   The Higginsville, Missouri Water Treatment Plant is a 2 million gallons per day
15   (MGD) treatment plant that draws water from a small surface water impoundment in
16   Missouri. The plant operates 12 hours a day and employs a two stage settling process with
17   conventional filtration. In 1994, the plant experienced a violation of the atrazine maximum
18   contaminant level (MCL). The system eventually switched to GAC caps on their filters to
19   counter the problem.
20
21   The source for the Higginsville plant is an impoundment that collects surface
22   runoff from nearby agricultural areas. It has high hardness and TOC. The average source
23   water quality is described in Exhibit B.12.
24
25
26   **Exhibit B.12 Average Source Water Quality**

Parameter	Average Value
pH	8.1
Alkalinity	89 mg/L as $CaCO_3$
Hardness	129 mg/L as $CaCO_3$
Turbidity	18 NTU
TOC	6 mg/L

27
28

[1]For an example of GAC used as a biological filter after ozonation, see Case Studies 9 and 10.

1   **The Original Treatment Process at the Higginsville WTP**
2
3   Exhibit B.13 displays a schematic of the treatment scheme at the Higginsville plant.
4   The plant adds chlorine dioxide to the raw water to control taste and odor problems.
5   Copper sulfate is also added occasionally to control biological blooms that lead to taste and
6   odor problems. The water is then pumped to a first set of coagulation and settling basins.
7   An average of approximately 40 mg/L of alum and 1.7 mg/L of cationic polymer are
8   added. Lime and fluoride are added to a second flash mix prior to the water passing
9   through a second set of coagulation and sedimentation basins. The water is then filtered
10 through dual media filters. Chlorine is added both prior to the filters and to a 0.5 million
11 gallon clearwell after the filters.
12
13   When the utility first experienced violations of the atrazine MCL in 1994, it added
14 powdered activated carbon (PAC) in the first flash mixer to combat the problem. Although
15 PAC did lower atrazine concentrations below the MCL, it was limited in removal
16 capabilities because of the short contact time.
17
18   **Exhibit B.13 Higginsville Water Treatment Plant**
19

Chlorine Dioxide

Alum

(Copper Sulfate

 and/or PAC if
needed)

Lime

Polymer

Fluoride

Flash
Mix #1

Coagulation
Basin #1

Sedimentation
Basin #1

Flash
Mix #2

Coagulation
Basin #2

Sedimentation
Basin #2

Chlorine

Chlorine

0.5 MG
Clearwell

Dual
Media
Filters
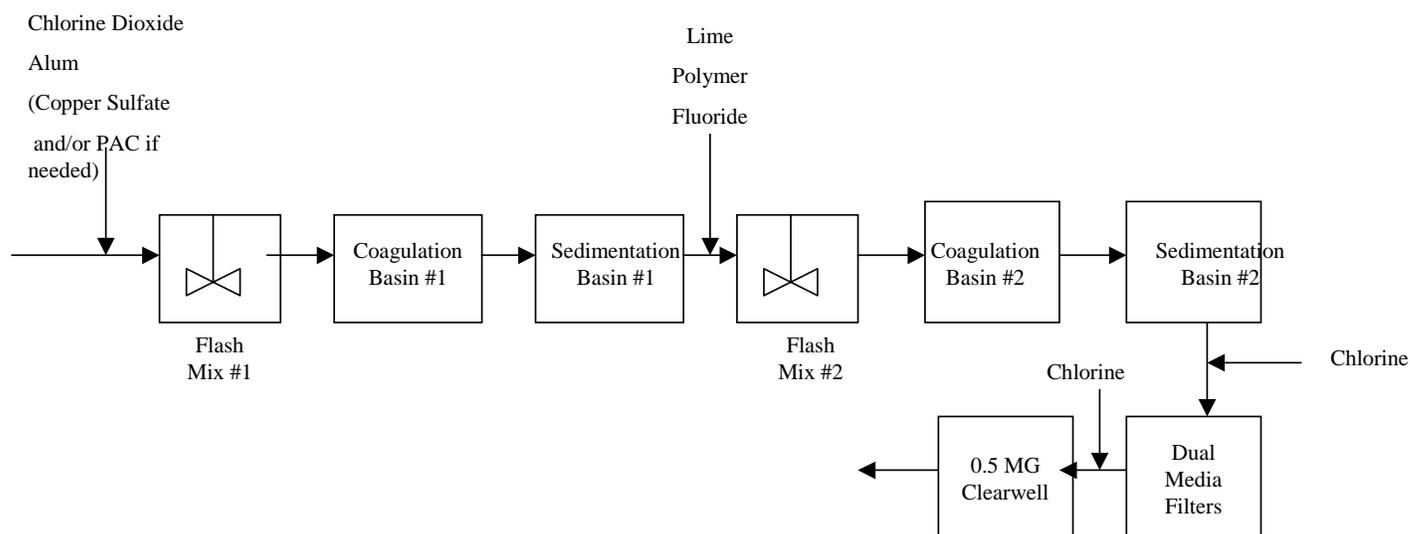
20
21 **Simultaneous Compliance Issue Faced by the Utility**
22
23   The utility was in violation of the atrazine MCL. In addition, high TOC levels
24 were contributing to total trihalomethane (TTHM) levels which averaged around 80 mg/L,
25 which could cause problems with Stage 1 and Stage 2 DBPR compliance. Although PAC
26 provided a temporary solution to the atrazine problem, it was not desirable as a long term

1   treatment method because of high amounts of sludge. The system also faced periodic taste
2   and odor episodes.
3
4   **Steps Taken by the Utility**
5
6   The utility replaced the anthracite in its dual media filters with GAC in an attempt
7   to reduce atrazine concentrations and lower TOC and DBPs. The pre-chlorination residual
8   was also reduced to 0.1 mg/L to prevent degradation of the GAC. Twenty four inches of
9   GAC were placed on top of the sand and gravel base of the filters. The total EBCT was
10   7.5 minutes.
11
12   **Results of the Steps Taken**
13
14   When the GAC caps were first installed, atrazine levels dropped to below detection
15   and DBP precursors as measured by ultraviolet light adsorption at 254 nm (UV_{254}) dropped
16   by 50 percent. After about 3 months of operation the removal rates dropped. Removal
17   rates eventually settled at 30 to 60 percent atrazine removal and 20 percent UV_{254} removal
18   after about 6 months of operation. The atrazine concentrations were always below the
19   MCL of 3 mg/L, averaging between 1 and 2 mg/L. The hydraulic performance of the filter
20   was unaffected by the change to the GAC cap. Turbidity values leaving the filters were
21   comparable to values produced previously with the anthracite filters.
22
23   **Implementation and Operational Issues Faced by the Utility**
24
25   Adsorption of atrazine and other organics onto the GAC gradually decreased
26   removal rates over time. A build up of inorganic precipitates, largely calcium, was seen on
27   the GAC, which also contributed to decreased removal rates. The removal rates can be
28   restored by regenerating or replacing the GAC, though this can be expensive.
29
30   It is possible that initial removal was due to adsorption and biological activity was
31   later established. If this were the case, subsequent removal resulted from a combination of
32   adsorption and biological degradation. If biological activity is suspected, care should be
33   taken not to change the operational characteristics (e.g., fluidized bed heights, backflow
34   rates) since changes in these operational parameters might impact removal performance.
35
36   There was a trade-off between removal of atrazine and removal of UV_{254}. Lower
37   pH favored UV_{254} removal at the expense of atrazine removal, while high pH had the
38   opposite effects.
39
40   The system still experiences occasional taste and odor episodes. This is most likely
41   caused by taste and odor causing compounds passing through the filters because GAC
42   contact time and design are not optimal for taste and odor control. These episodes have
43   been dealt with by adding PAC prior to the filters.

1
2   **Lessons Learned From this Case Study**
3
4   • GAC caps can be used effectively to reduce pesticide and TOC concentrations.
5
6   • Adsorption of organic compounds by GAC is complicated and depends on the
7   concentrations of other adsorbing compounds present in the source water. Bench
8   scale tests should be done on the specific source water to determine if GAC itself, as
9   well as different brands of GAC, will be effective with that water.
10
11   • The pH of the water can impact GAC removal rates for different organic compounds.

<div align="center">

Case Study # 8
Nanofiltration Membrane Technology for TOC Removal
PBCWUD Water Treatment Plant #9
West Palm Beach, Florida

</div>

1
2
3
4
5
6
7   The Palm Beach County Water Utilities Department (PBCWUD) Water Treatment
8 Plant # 9 (WTP #9) was originally constructed in 1971 by private developers and was
9 acquired by the County in 1983. The original plant utilized lime softening, rapid sand
10 filtration, short-term free chlorination for biological growth control in the filters and
11 chloramination as the secondary disinfection process. The facility had a maximum day
12 flow capacity of 13.45 MGD, and was comprised of three treatment trains with capacities
13 of 1 MGD, 3 MGD and 10 MGD.
14
15   Initially, the plant provided water service to the local area, but it was later
16 incorporated into the regional water distribution system to provide potable water for the
17 southern portion of the PBCWUD Service Area. Recognizing the growing demands for
18 water in the area and the implementation of new drinking water standards, PBCWUD
19 administered a construction contract for a new 27 MGD nanofiltration plant that was
20 awarded in 1999. Nanofiltration will be used for removal of hardness, color, TOC, and its
21 related chlorinated DBPs, which are commonly found in South Florida ground water. The
22 plant started operational testing in November 2001.
23
24   This case study provides an example of the following simultaneous compliance
25 issues that can be associated with nanofiltration membrane technology:
26
27   • DBP Rules - ability to remove DBP precursors
28   • LCR - ability to provide a non-corrosive water in the PBCWUD distribution
29   system
30   • Secondary Drinking Water Standards - ability to provide an aesthetically
31   pleasing water to PBCWUD customers
32

Introduction

33

34
35   The mission of PBCWUD is to provide the highest quality drinking water service
36 in a fiscally and environmentally sound manner. In the last decade, with the enforcement
37 of the Secondary Drinking Water Standards and the Stage 1 D/DBPR in the State of
38 Florida, PBCWUD's capital improvement strategy for new water treatment plants has been
39 focused on nanofiltration membrane technology. Membrane water treatment technology is
40 cost competitive with traditional conventional treatment methods while producing higher
41 quality potable water; consequently, becoming the dominant water treatment technology in
42 South Florida.

1
2   In May of 2003, PBCWUD completed Phase I construction of a new, and one of
3   the largest in the world, nanofiltration membrane treatment plant (WTP #9) with a
4   maximum capacity of 27 million gallons per day (MGD) finished water, including 23
5   MGD of membrane permeate and 4 MGD of raw blend water. As stated previously, the
6   primary reason for the membrane softening is for removal of hardness, color, TOC, and its
7   related chlorinated DBPs.
8
9   The raw water supply for WTP #9 is water from the local surficial Biscayne
10   Aquifer. The surficial aquifer system provides the water source for most public water
11   supply wellfields in southeastern Florida. The aquifer system is generally unconfined and
12   extends from land surface to a depth of approximately 330 feet below land surface (bls).
13   The ground water is generally colored due to organics, hard and alkaline with varying
14   amounts of dissolved iron and hydrogen sulfide. Typical ranges of water quality found in
15   the Biscayne Aquifer are shown in Exhibit B.14.
16
17
18   **Exhibit B.14 Typical ranges of raw water quality in the Biscayne Aquifer**

Water Quality Parameter	Units	Range of Values
pH	Standard Units	7.0-7.5
Alkalinity	Mg/L as CaCO3	200-240
Chloride	Mg/L	<250
Total Dissolved Solids	Mg/L	250-600
Hardness	Mg/L as CaCO3	225-275
Sulfate	Mg/L	15-25
Total Organic Carbon	Mg/L	10-12
Color	Color Units	360-400

19
20
21   **The New Treatment Process at Water Treatment Plant #9**
22
23   The treatment train for WTP #9 is shown in Exhibit B.15. The raw water supplied
24   to WTP #9 is taken from the shallow surficial aquifer through a series of 24 wells.
25   Pretreatment includes a sand strainer which removes bulk sand from the raw water stream,
26   acid injection to control pH to 5.0-5.9, and 5-micron cartridge filters to remove particulates
27   greater than 5 microns. Six membrane feed pumps located after the micron filters boost
28   the feed water pressure to 125-132 psi. The nanofiltration membrane building includes
29   eight membrane treatment trains where each one has two stages with 47 and 22 pressure
30   vessels, respectively. The degasifier/odor control system functions to remove hydrogen
31   sulfide and carbon dioxide from the permeate water (product water from the membranes)
32   and to prevent the emission of odors into the atmosphere. A sodium hypochlorite system

1   supplies dilute liquid chlorine for disinfection. Six high service pumps supply water to the
2   distribution system. Post-storage chemical injection points for ammonia, chlorine and
3   caustic soda are included in the system to allow final disinfection and/or pH adjustment
4   before the finished water enters the distribution system. The water entering the
5   distribution system is monitored for chlorine residual, pH, pressure, and flow. The
6   impurities removed by the membrane softening trains are consolidated into a concentrate
7   stream and discharged through three-concentrate booster pumps into one deep injection
8   well.
9
10 **Treatment Steps Taken by Palm Beach County**
11
12   • Pretreatment of sand strainer, acid injection, cartridge filtering
13
14   • Eight nanofiltration membrane treatment trains
15
16   • Degasification and odor control
17
18   • Dilute chlorine disinfection
19
20   • Post-storage final disinfection and/or pH adjustment and control
21
22   • Distribution system monitoring
23
24 **Simultaneous Compliance Issues Faced by the Utility**
25
26   Nanofiltration membranes remove organic compounds in a molecular weight range of
27 200 to 20,000 Daltons and reject selected salts (typically divalent). Nanofiltration economically
28 softens water without the use of salt-regenerated systems and provides unique organic removal
29 capabilities. While effective in removing organic constituents or DBP precursors, the
30 nanofiltration membrane rejects selected salts, producing treated water with low total dissolved
31 solids (TDS). Low TDS water has poor buffering capacity and can lead to low pH water, which
32 is corrosive to metal pipes. Generally, an alkalinity below 25 mg/L as $CaCO_3$ (0.5 meq/l) can be
33 problematic for corrosion of piping (AWWARF and DVGW-Technologiezentrum Wasser 1996).
34 This chemically unstable water can result in compliance issues with the Secondary Drinking
35 Water Standards and the LCR.
36 .

Exhibit B.15 Water Treatment Plant #9 Treatment Train

1
3
5
7
9
11
13
15
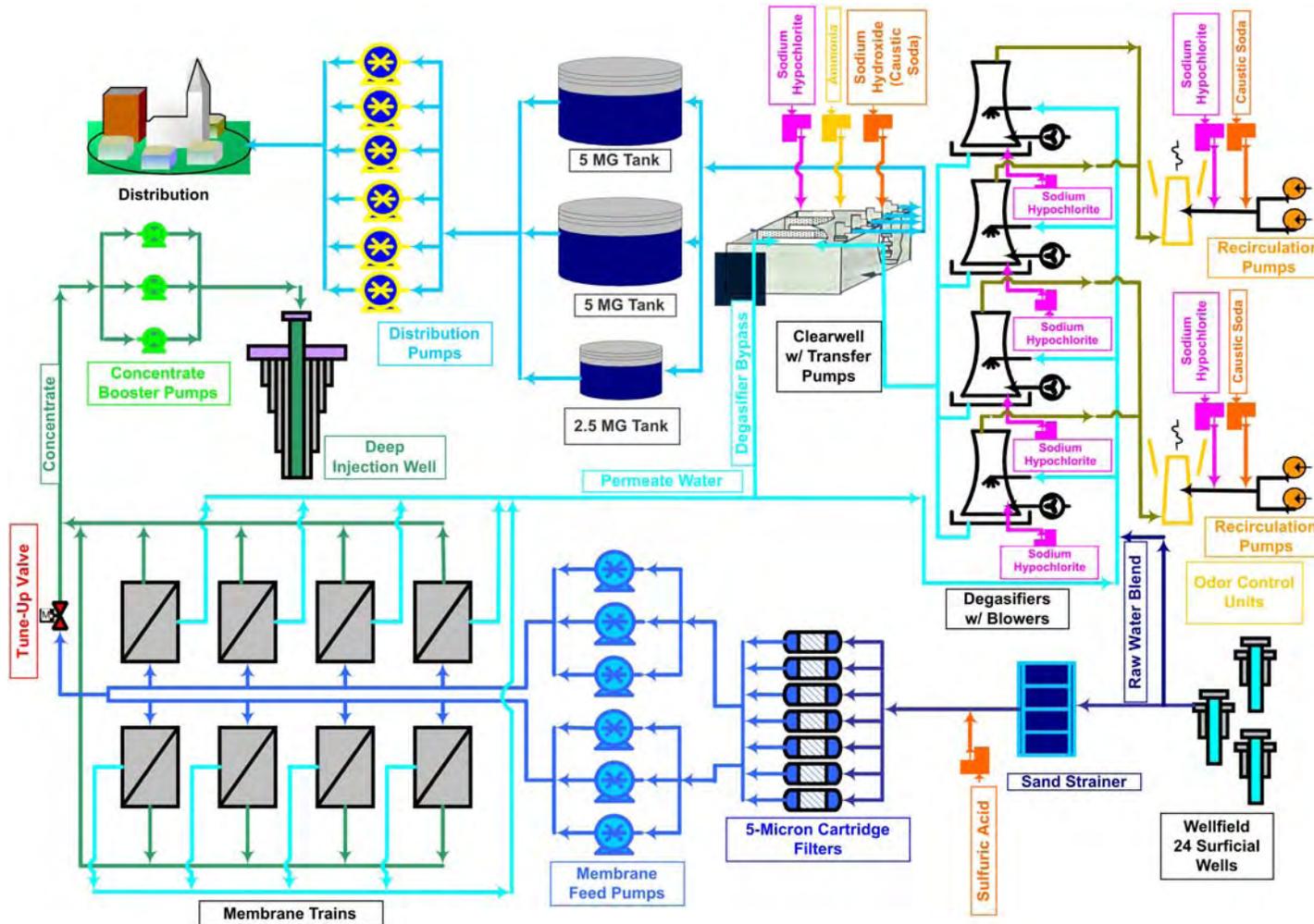
1   **Steps Taken by the Utility**
2
3   Steps taken by the utility to overcome the potential simultaneous compliance issues
4   discussed above occur primarily in the post-treatment process. The post-treatment process
5   is mainly taking place in the clearwell complex area as shown in Exhibit B.16. The
6   clearwell complex consists four major processes: 1) de-gasification process for de-
7   gasification of hydrogen sulfide and carbon dioxide from the permeate solution, 2) odor
8   control process to remove hydrogen sulfide from the air, 3) clearwell disinfection process
9   to create free and combined chlorine, and 4) transfer pump process to discharge the post-
10 treated water to the storage tanks.
11
12   Prior to the de-gasification process, approximately 4 MGD of raw water is
13 introduced into the treatment train to blend with the 23 MGD of treated water. Blending of
14 this raw water introduces some of the divalent salts back into the water that had been
15 previously rejected by the membrane. This provides a more chemically-stable finished
16 water.
17
18   Permeate water from the nanofiltration trains contains excessive amounts of carbon
19 dioxide and hydrogen sulfide; therefore, 4 identical de-gasifier towers with air blowers in
20 the clearwell complex function to remove carbon dioxide (CO_2) and hydrogen sulfide
21 (H_2S) from the permeate water with the air stripping process. Sodium hypochlorite is
22 injected into the permeate water before entering into the de-gasifiers for disinfection. The
23 towers are of the forced draft, randomly packed bed, counter flow type.
24
25   The de-gasifiers are designed for maximum influent pH of 6 std. units; influent H_2S
26 with concentration of 1.3 mg/L and removal efficiency of 92 percent; and influent CO_2
27 with concentration of 77 mg/L and with removal efficiency of 93.5 percent.
28
29   The stripped permeate is treated with a chlorine solution and ammonia for
30 secondary disinfection and caustic soda for pH adjustment.
31
32 **Results of the Steps Taken**
33
34   The resulting finished water quality is listed in Exhibit B.16.
35

1   **Exhibit B.16 Typical ranges of distribution system water quality**
2

Water Quality Parameter	Units	Range of Values
Total Trihalomethanes	ppb	ND-55.3
Haloacetic Acids	ppb	ND-51.4
pH	Standard Units	8.5-9.0
Alkalinity	mg/L as CaCO3	30-50
Chloride	mg/L	17.2-110
Total Dissolved Solids	mg/L	90-300
Hardness	mg/L as CaCO3	40-60
Sulfate	mg/L	6.0-19.5
Total Organic Carbon	mg/L	<0.5
Color	Color Units	1-7
Lead	ppb, 90th percentile	3
Copper	ppm, 90th percentile	0.134

3
4   As shown in Exhibit B.16, all Secondary Drinking Water Standards, DBP Rule MCLs,
5   and LCR Action Levels are met.
6
7   **Implementation and Operational Issues Faced by the Utility**
8
9   The utility experienced two serious problems in bringing the nanofiltration membrane
10   treatment plant online. The most serious problem involved numerous leaks in the acid feed
11   system. As a result of the leaks, the acid system had to be completely rebuilt during the first year
12   of operation.
13
14   The other problem involved the micron cartridge filter housings and the string wound
15   filter. The filter housings use a single open end cartridge with a stainless steel spring on the
16   other end to keep tension on the cartridge, holding it in place. In this case, the filters sagged in
17   the middle causing them to pull out of the socket. With the filter out of place, sand and debris
18   accumulated on the membranes. This problem was eliminated by modifying the cartridge
19   housings with a center bracket to support the filters. With these two modifications, the treatment
20   plant has worked very well and continues to produce very high quality water.
21
22   **Lessons Learned From This Case Study**
23
24   •   Nanofiltration economically softens water without the use of salt-regenerated systems
25   and provides unique organic removal capabilities thereby removing disinfection
26   byproduct precursors.
27

- Blending a portion of the raw water with treated water and the de-gasification process significantly enhances the aesthetic qualities of the finished water and results in a more chemically stable water. This enables PBCWUD to provide their customers with water that complies with both the LCR and the Secondary Drinking Water Standards.

References

AWWA. 1999. Reverse Osmosis and Nanofiltration. AWWA Manual M46.

Glucina, K., A. Alvarez, and J.M. Laine. 2000. Assessment of an integrated membrane system for surface water treatment. Proceeding of the conference in drinking and industrial water production. 2: 113-122. Italy, October 2000.

HDR Engineering, Inc. 2001. Handbook of Public Water Systems. 2nd ed. Pages 509-510.

Montgomery Watson Inc. 1998. Palm Beach County Water Utilities Department Water Treatment Plant No. 3 Membrane Softening Facility Operations Manual Final Report. Pages 4-19 to 4-20.

Panayides, N., Operational Procedures of a New 27 MGD Nanofiltration Membrane Water Treatment Plant (WTP No. 9) in South Florida. Palm Beach County Water Utilities Department.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21   This page intentionally left blank.

1 <div align="center">**Case Study #9**</div>
2 <div align="center">**Modifying Chloramination Practices to Address Nitrification Issues**</div>
3 <div align="center">**Ann Arbor Utilities[2]**</div>
4 <div align="center">**Ann Arbor, Michigan**</div>
5
6
7   This case study demonstrates how a utility modified chloramination practices to address
8 nitrification problems in the distribution system to be in compliance with the Stage 1 DBPR and
9 the TCR.
10
11 **Introduction**
12
13   The City of Ann Arbor operates a two-stage lime softening plant (50 million gallons per
14 day (MGD) design flow) that treats a blend of surface water and ground water. It serves
15 approximately 115,000 people. The influent to the plant consists of a blend of Huron River
16 water (approximately 85 percent) and well water (approximately 15 percent). Typical water
17 quality parameters for raw river water and well water, prior to any treatment modifications, are
18 presented in Exhibit B.17. The water entering the plant has high alkalinity (average alkalinity of
19 314 mg/L as $CaCO_3$), with high TOC levels (average 6 mg/L).
20

---

[2] this system is also used in Case Study #10 Ozonation

1
2 **Exhibit B.17 Summary of Relevant Water Quality Parameters at Ann Arbor Before**
3 **Treatment Modifications**
4

Water Quality Parameters	Location[1]			
	River	Well	Blended Influent	Effluent
TOC (mg/L) Minimum Average Maximum	5.5 6.9 8.7	1.0 2.2 5.9	5.1 6.0 8.1	2.1 3.0 3.5 (3.7)[2]
pH Minimum Average Maximum	7.9 8.1 8.2			9.3 (9.1)[2] 9.4 9.7
Alkalinity (mg/L as CaCO$_3$) Minimum Average Maximum	205 215 228	301 314 335	218 234 250	28 39 48
Total Coliforms (#/100 ml) Minimum Average Maximum	62 781 2,890	0 0 0		
***Cryptosporidium* (# oocysts/100 gallons)** Minimum Average Maximum	ND 114 1,739			ND ND ND

5 Notes:
6 1. Data collected between July 1994 and June 1995; based on monthly (average) data.
7 2. Minimum or maximum values (in parentheses) represent minimum or maximum of all measurements, not
8 limited to monthly average data.
9 3. ND = Non Detectable
10
11
12 **The Treatment Process at the Ann Arbor WTP**
13
14   The treatment plant is a 50 MGD two-stage lime softening plant that uses chloramines for
15 primary disinfection. The average operating flow is 20 MGD. Exhibit B.18 shows a schematic
16 of the treatment plant. Raw river water is disinfected with chlorine, then chlorine is added again
17 with ammonia after filtration to form chloramines. The free chlorine contact time is minimal.
18 The water is softened with lime (average dose = 187 mg/L as CaCO$_3$), at a pH slightly above 11.

1   From April through November well water is blended with softened water from the first stage
2   clarifier effluent and recarbonated (i.e., addition of CO_2) to bring the pH down to around 10. It
3   then enters the second-stage clarifier. A cationic polymer is added at this point (average dose
4   0.62 mg/L) to enhance settling. The water is then recarbonated (i.e., CO_2 is added) down to a pH
5   slightly greater than 9, and sodium hexametaphosphate is added to facilitate corrosion control.
6   The water is then filtered (granular activated carbon (GAC)/sand dual-media filters). After
7   filtration, sodium hypochlorite and ammonia are added to form chloramines and the finished
8   water is distributed at an average pH of 9.4.
9
10   From December through March the chemical application points are similar to those
11   during the summer months. However, the well water is blended with the river water prior to the
12   first stage of the lime softening process to raise the water temperature and improve sludge
13   dewatering.
14
15   The chloramines dose ranged from 4.1-6.2 mg/L and *Giardia* log inactivation by
16   chloramination ranged from 0.5 to1.0 logs.
17
18
19   **Exhibit B.18 Ann Arbor Water Treatment Plant**
20

21
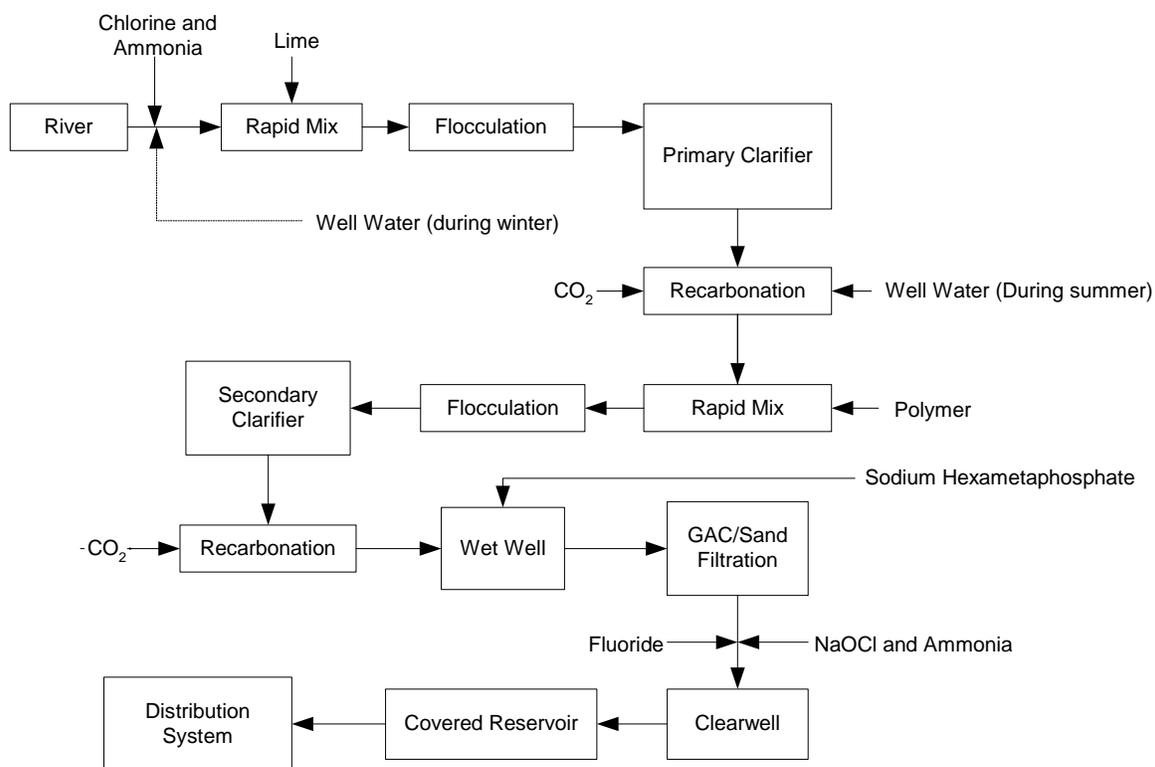
1
2   **Simultaneous Compliance Issue Faced by the Utility**
3
4   The system switched to chloramines to reduce TTHM formation and to be in compliance
5   with the Stage 1 Disinfectants/Disinfection Byproducts Rule (D/DBPR). However, the use of
6   chloramines can result in the presence of ammonia in the distribution system if the proper
7   chlorine to ammonia (as nitrogen) ratio is not maintained. This increases the potential for
8   biological nitrification. Nitrification can result in a loss of combined chlorine residual, and result
9   in sharp increases in HPC bacteria. This increases the chances of a TCR violation.
10
11   **Steps Taken by the Utility**
12
13   To cope with the nitrification problem, Ann Arbor expanded its monitoring program and
14   made several operational and facility adjustments to improve ammonia feed rate control. The
15   chlorine to ammonia (as nitrogen) ratio was maintained at 4.75:1, with a target level for free
16   ammonia entering the distribution system of 0.15 mg/L. Warning and action levels for nitrite in
17   the system were set at 0.025 and 0.050 mg/L, respectively.
18
19   As soon as the utility became aware of its nitrification problem, it attempted to control it
20   by controlling the concentration of free ammonia reaching the filters. No changes were made to
21   the existing treatment configuration. However, the system made several operational changes.
22   Ammonia dosage at the headworks was reduced so that less than 0.15 mg/L of free ammonia
23   remained in the water when it entered the filters. Along with this, distribution lines were flushed
24   at low velocity until an average combined chlorine residual of approximately 3 mg/L was
25   achieved. The Stage 1 DBPR specifies a running annual average maximum residual disinfectant
26   level (MRDL) for chlorine of 4.0 mg/L (as Cl_2).
27
28   During the summer months (i.e., June to September), the system switched back to
29   chlorination. This was achieved by simply shutting down ammonia addition after filtration and
30   adjusting the chlorine feed rate. This would ensure that nutrient levels (i.e., ammonia) in the
31   distribution system were low during the warmer months, when the temperature was most
32   conducive to the rapid growth of nitrifying organisms. This would decrease biological activity in
33   the distribution system.
34
35   **Results of the Steps Taken**
36
37   As a result of these steps, nitrite concentrations in the distribution system were below
38   detection level. Also, HPC levels dropped significantly in five of the six locations where
39   nitrification had previously been found. The system did see an increase in TTHM formation
40   during the summer months. However, careful monitoring, dosing, and complementary hydrant
41   flushing (see next paragraph for details) resulted in compliance with the Stage 1 DBPR. The
42   average and maximum TTHM in the finished water were 24 and 39 μg/L, respectively (based on
43   the monthly TTHM data collected between July 1994 and June 1995).

Implementation and Operational Issues Faced by the Utility

Although switching to free chlorine during the summer was effective for controlling nitrification, it appeared to result in higher levels of heterotrophic and coliform bacteria than when the water was chloraminated. At the same time, increasing the chlorine dose during the summer months increased TTHM concentrations. As a result, the system decided to continue disinfecting with chloramines and pursue a more aggressive hydrant flushing program to control bacterial re-growth in the distribution system.

Analysis revealed that one of the prime causes of nitrification could have been the switch to a GAC/sand dual-media filter from a pure sand filter. The ammonia added before the water reached the filters could have provided a nutrient source sufficient for nitrifying bacteria to attach, establish, and proliferate within the GAC media. Such a condition could have allowed the nitrifying organisms to pass through the filter and seed the distribution system if they survived the chloramine disinfection.

Lessons Learned From this Case Study

- Controlling nitrification in the distribution can be a challenge for utilities switching to chloramines.

- Carrying a chloramine residual through the treatment plant might increase distribution system problems with biological nitrification.

- The most common strategies for controlling nitrification are listed below.

  o Improving ammonia feed rate control to limit the free ammonia levels entering the distribution system.
  o Implementing a comprehensive distribution system flushing and monitoring program.
  o Having an alternative disinfection strategy for the warmer months of the year.

- Systems adding ammonia prior to a GAC filter may be more likely to face nitrification in the distribution system.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

This page intentionally left blank.

1   **Case Study #10**
2   **Ozonation**
3   **Ann Arbor Utilities[3]**
4   **Ann Arbor, Michigan**
5
6
7   This case study demonstrates how a utility switched to ozonation to meet the Interim
8   Enhanced Surface Water Treatment Rule (IESWTR) and the Stage 1 and 2 DBPR regulations,
9   and simultaneously controlled microbial regrowth potential in the distribution system to be in
10   compliance with the TCR.
11
12   **Introduction**
13
14   The City of Ann Arbor serves approximately 115,000 people, and operates a two-stage
15   lime softening plant (50 MGD design flow) that treats a blend of surface water and ground water.
16   In 1990, for the reasons outlined below, the Ann Arbor plant decided to switch from
17   chloramines to ozonation for primary disinfection.
18
19   •   Ozonation would meet IESWTR CT requirements for viruses at low temperatures.
20
21   •   In addition to complying with the IESWTR, ozonation was expected to allow the
22   plant to comply with Stage 1 and 2 DBPRs.
23
24   •   Ozonation was also expected to improve taste and odor.
25
26   The influent to the plant consists of a blend of Huron River water (approximately 85
27   percent) and well water (approximately 15 percent). Typical water quality parameters for raw
28   river water and well water, prior to any treatment modifications, are presented below in Exhibit
29   B.19. The water entering the plant has high alkalinity (average influent alkalinity of 314 mg/L as
30     $CaCO_3$), with high TOC levels (average 6 mg/L).
31

---

[3] this system is also used in Case Study #9 Modifying Chloramination Practices to Address Nitrification
Issues.

1
2   **Exhibit B.19 Summary of Relevant Water Quality Parameters at Ann Arbor Before**
3   **Treatment Modifications**

Water Quality Parameters	Location[1]			
	River	**Well**	**Blended Influent**	**Effluent**
TOC (mg/L) Minimum Average Maximum	5.5 6.9 8.7	1.0 2.2 5.9	5.1 6.0 8.1	2.1 3.0 3.5 (3.7)[2]
pH Minimum Average Maximum	7.9 8.1 8.2			9.3 (9.1)[2] 9.4 9.7
Alkalinity (mg/L as CaCO$_3$) Minimum Average Maximum	205 215 228	301 314 335	218 234 250	28 39 48
Total Coliforms (#/100 ml) Minimum Average Maximum	62 781 2,890	0 0 0		
Cryptosporidium (# oocsts/ 100 gallons) Minimum Average Maximum	ND 114 1,739			ND ND ND
TTHM (μg/L) Minimum Average Maximum				14 24 39
HAA5[4] (μg/L) Minimum Average Maximum				4.2 16 21

4   Notes:
5   Data collected between July 1994 and June 1995; based on monthly (average) data.
6   Minimum or maximum values (in parentheses) represent minimum or maximum of all measurements, not limited
7   to monthly average data.
8   ND = Non Detectable
9   Data collected quarterly between October 1995 and May 1996.
10

1
2   **The Original Treatment Process at the Ann Arbor WTP**
3
4   The original treatment plant was a 50 MGD two-stage lime softening plant that used
5   chloramines for primary and secondary disinfection. The average operating flow was 20 MGD.
6   Exhibit B.20 shows a schematic of the treatment plant, prior to the modifications. Raw river
7   water was disinfected with chlorine, followed by ammonia addition to form chloramines. The
8   free chlorine contact time was minimal. The water was softened with lime (average dose = 187
9   mg/L as $CaCO_3$), at a pH slightly above 11. From April through November, well water was
10   blended with softened water from the first stage clarifier effluent and recarbonated (i.e., addition
11   of CO_2) to bring the pH down to around 10. It then entered the second-stage clarifier. A cationic
12   polymer was added at this point (average dose 0.62 mg/L) to enhance settling. The water was
13   then recarbonated down to a pH slightly greater than 9 and sodium hexametaphosphate added, to
14   facilitate corrosion control. It was then filtered (GAC/sand dual media filters). After filtration,
15   sodium hypochlorite and ammonia were added to boost the level of chloramines. The finished
16   water was distributed at an average pH of 9.4.
17
18   From December through March the chemical application points were similar to those
19   during the summer months. However, the well water was blended with the river water prior to
20   the first stage of the lime softening process to raise the water temperature and improve sludge
21   dewatering.

1   **Exhibit B.20 Ann Arbor Water Treatment Plant Before Treatment Modifications**
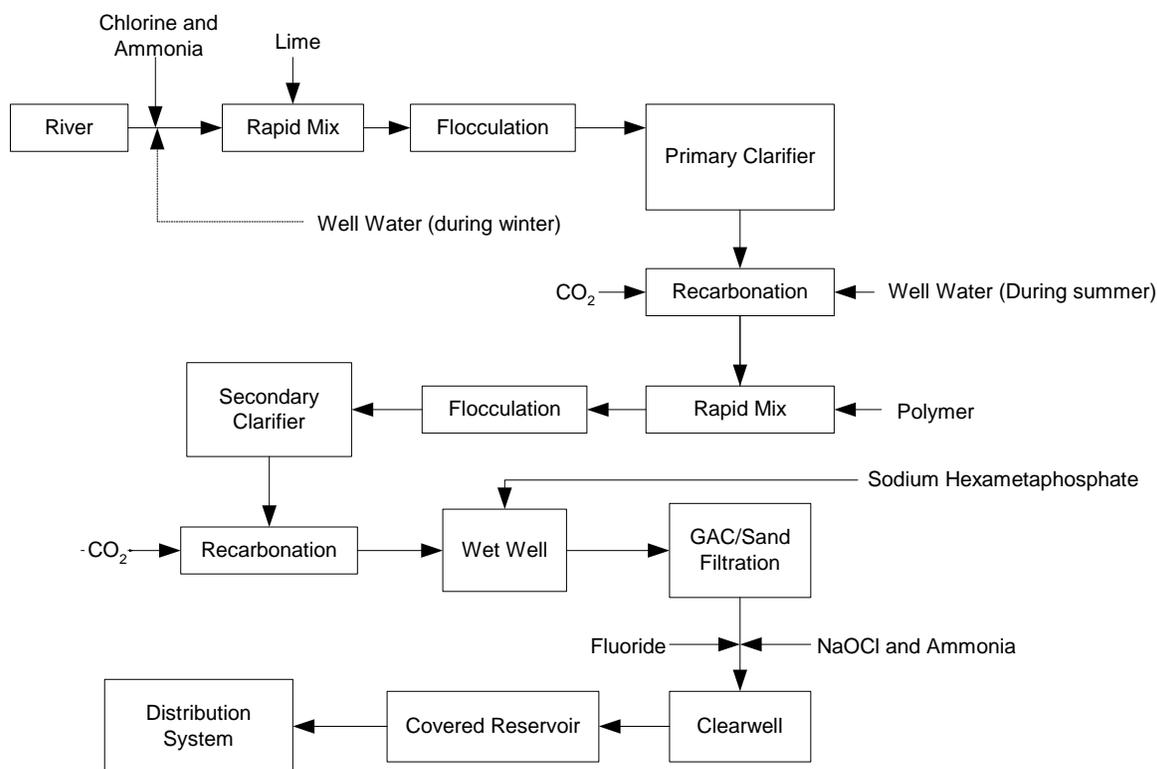
2
3
4 **Simultaneous Compliance Issue Faced by the Utility**

5

6   Application of ozone would lower the formation of TTHM and HAA5s and enhance the
7 ability to meet minimum virus and *Giardia* inactivation levels (to be in compliance with the
8 IESWTR). However, ozonation could lead to an increase in the AOC levels in the finished water,
9 resulting in potential microbial regrowth in the distribution system and non-compliance with the
10 TCR.

11

12 **Steps Taken by the Utility**

13

14   The utility switched to ozonation, followed by biofiltration, in order to address the
15 simultaneous compliance issue. They no longer pre-chlorinate or pre-chloraminate.

16

17   Before switching to ozone, the operators of Ann Arbor's system contacted known ozone
18 facilities and talked with their engineers and operators to learn what features, in retrospect, they
19 wish they had installed when they installed the ozone. Based on these discussions, some features
20 missing from previous plant designs were incorporated into the Ann Arbor system's design. One

1   example of such as a feature is the addition of waterproof hatches for direct access to the contact
2   chambers. This eliminated the need for roof entry, which is an important consideration for
3   system operators.
4
5   Overall process – Exhibit B.21 shows a schematic of the treatment plant after the
6   modifications. Changes made to the original treatment train are outlined below.
7
8   •   Ozonation is now the primary disinfection step. The pre-chlorination step was
9   eliminated.
10
11   •   The first point of disinfectant addition (i.e., ozonation) is after the secondary clarifier,
12   and recarbonation. The ozonation pH is 8.0.
13
14   •   After ozonation, sodium hydroxide is added to raise the pH of the water to 9.4 prior to
15   adding sodium hexametaphosphate as a corrosion inhibitor.
16
17   •   The original dual media (GAC/sand) filters are now operated as biofilters. To help
18   inactivate HPC bacteria shed from the filters, filter effluent is disinfected with an
19   average chloramine dose of 3.5 mg/L, and held for approximately 3 hours in the
20   covered reservoir.
21
22   *Ozonation Details*
23
24   There are 8 ozone contact cells with an overall contact time of 16.8 minutes. The system
25   is operated at a 6 to 10 percent gas concentration. An off-gas recycle system applies ozone to the
26   first cell, which reduces demand in subsequent cells but does not produce an ozone residual. The
27   goal is to achieve a residual of 0.1 mg/L or greater in the first cell, and to maintain sufficient
28   residuals in subsequent cells, to meet the target CT.
29

1   **Exhibit B.21 Ann Arbor Water Treatment Plant After Treatment Modifications**
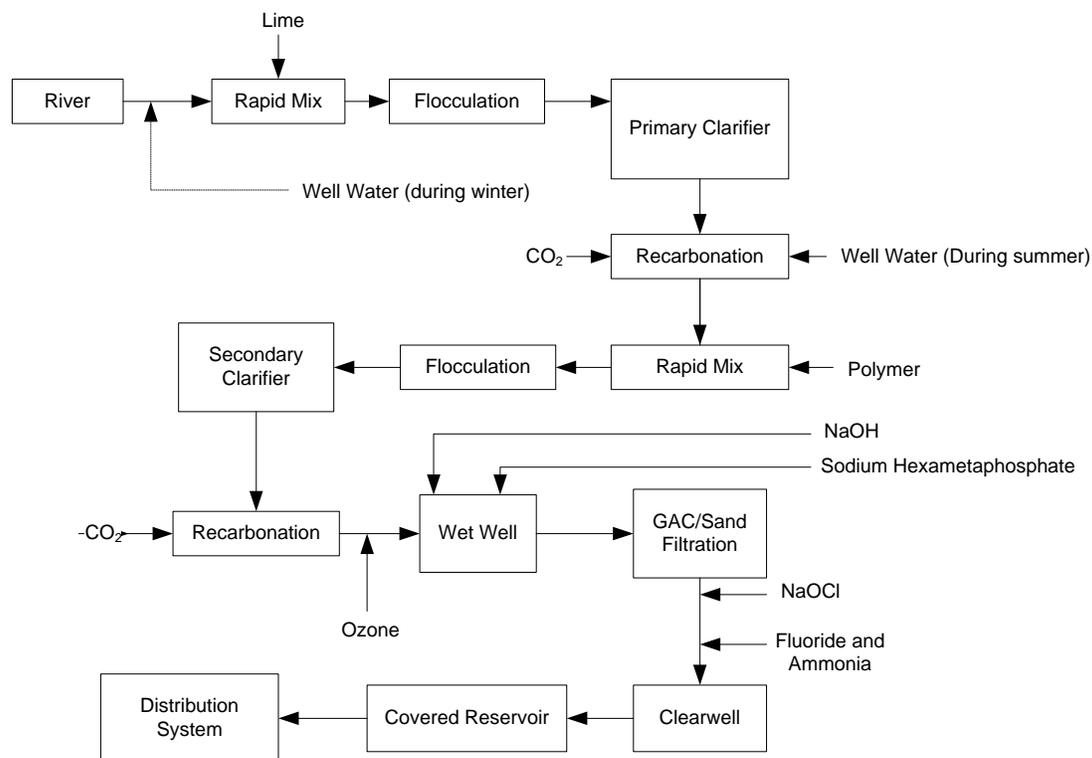
2
3
4   *Biofiltration Operations*
5
6   The filter consists of 18 inches of GAC and 6 inches of sand. The filtration rate varies
7   from 0.76 to 3.0 gpm/ft^2. The empty bed contact time (EBCT) of the GAC is 3.7 minutes at
8   design flow and 7.4 minutes at typical flow. Filter backwash frequency is governed by: (a)
9   effluent turbidity exceeding 0.2 nephelometric turbidity units (NTU), (b) number of hours in
10   service (usually 80 hours is the cut-off point), and (c) acceptable headloss limits (which is
11   usually not a controlling criterion). The backwash is performed using finished chloraminated
12   water.
13
14   **Results of the Steps Taken**
15
16   •   DBP reductions - Exhibit B.22 shows the TTHM and HAA5 concentrations before
17   and after the modifications at the Ann Arbor plant. Clearly, ozonation resulted in a
18   significant drop in TTHM and HAA5 concentrations, resulting in no compliance
19   problems with the Stage 1 and Stage 2 DBPRs.
20
21   •   Bromate formation - Ozonation can oxidize bromide to bromate, which is regulated
22   by the Stage 1 DBPR at an MCL of 10 μg/L. Influent bromide concentrations at the

1   ozonation plant ranged from 27 to 80 μg/L, with an average of 67 μg/L. The well
2   contributes more to the bromide levels than the river water. The average bromide
3   concentration in the ground water is 100 μg/L, and the Huron River water has an
4   average bromide concentration of 59 μg/L. The bromate levels in the finished water
5   ranged from 2 to 8 μg/L, with an average of 3 μg/L. At its current level of bromate
6   formation, Ann Arbor meets the bromate MCL.

7
8   • TOC removal - The average influent TOC to the plant after the modifications was 5.5
9   mg/L (with a range of 4.5-7.0 mg/L). The average effluent TOC was 2.7 mg/L (with
10 a range of 2.1-3.4 mg/L). Therefore, TOC removal ranged from 40 to 59 percent with
11 an average of 51 percent, which is quite similar to the TOC removals achieved before
12 implementing ozonation. The Stage 1 D/DBPR TOC removal requirements for
13 softening plants with an influent TOC >4.0-8.0 or >8.0 mg/L are 25 and 30 percent,
14 respectively (USEPA 1998a). The Ann Arbor plant exceeds these requirements.
15 Higher TOC removal has the advantage of lowering the ozone dose requirements
16 because the ozone applied is not used up by reactions with TOC.

17
18 **Exhibit B.22 DBP Formation Before and After Ozonation at Ann Arbor**
19

DBPs	Before Modification[1]	After Modifications[2]
TTHM (μg/L) Minimum Average Maximum	14 24 39	1.4 7.2 13
HAA5 (μg/L) Minimum Average Maximum	4.2 16 21	1.5 5.0 15
Bromate (μg/L) Minimum Average Maximum		2 3 or 4[3] 8

20 Notes:
21 1. Monthly TTHM data collected between July 1994 and June 1995; other DBP data collected quarterly between
22 October 1995 and May 1996.
23 2. Data collected in calendar year 1997; based on monthly or quarterly data.
24 3. Depending on whether the non-detects were set to zero or half the minimum detection level.
25
26
27 **Implementation and Operational Issues Faced by the Utility**
28
29 • Operator training and start-up - It took about 2 to 3 months for the operational staff to
30 be at ease with the new technology, and about 3 to 5 months for the plant to operate

1   optimally and smoothly. The change in treatment also changed the operational needs
2   of the plant; additional mechanics and instrumentation technicians were needed.
3   Additional resources had to be allocated to treatment operation and maintenance.
4
5   •   Sludge accumulation over diffusers - This caused fluctuating ozone residuals,
6   resulting in difficulty obtaining the required CT. The plant has been testing various
7   chemicals to improve secondary settling to reduce the impact of the sludge on the
8   ozone system.
9
10   •   Liquid Oxygen (LOX) vaporizers did not defrost well in winters, causing the system
11   to shut down due to low gas flow.
12
13   •   Optimizing biofiltration during winters - Extremely large seasonal fluctuations in
14   temperature have strongly governed treatment strategy at the Ann Arbor plant.
15   Average monthly river water temperature in 1997 ranged from 7.9 to 22^oC, with an
16   average of 14^oC. The lowest temperature in winter during the sampling period was
17   3^oC. Well water temperatures are fairly constant at 14^oC. After ozonation and
18   biofiltration, AOC content ranged from 40 to 210 μg C/L (average = 129 μg C/L).
19   During the summer, approximately 40 percent of AOC produced by ozonation was
20   removed during biofiltration, whereas in winter there was practically no removal.
21   This suggests poor biological activity on the filters in winter months. Ann Arbor
22   raises the temperature of the influent water in winter by mixing in a larger proportion
23   of ground water (24-29 percent versus 10-20 percent in the summer). It also
24   introduces well water at the head of the plant in winter to increase the water
25   temperature so that treatment processes like biofiltration are more effective.
26
27 **Lessons Learned From this Case Study**
28
29   •   Ozonation requires a high degree of operational expertise. The key to running a
30   successful ozonation treatment unit depends greatly on the operator being
31   comfortable with the new instrumentation and controls.
32
33   •   Ozonation may not be suitable for influent waters with high bromide concentrations.
34
35   •   Ozonation increases the AOC concentration in finished water. As a result,
36   biofiltration is required downstream of ozonation to ensure AOC removal and reduce
37   the opportunity for microbial regrowth in the distribution system. Failure to do so
38   may result in TCR violations. Biofiltration needs careful monitoring and
39   optimization, especially during winter when microbial activity is greatly reduced.
40   One operational strategy is to increase the proportion of ground water in the influent
41   surface/ground water blend during winter to ensure that treated water has a higher
42   temperature.

<div style="text-align:center">

Case Study #11
Ozonation and Biological Filtration
Sweeney Water Treatment Plant
Wilmington, North Carolina

</div>

This case study provides an example of a water system that upgraded its treatment plant by expanding its capacity from 15 MGD to 25 MGD and installing ozonation and biological filtration to improve compliance with IESWTR and LT2ESWTR regulations and to increase aesthetics and customer confidence.

The majority of the information for this case study was found in Najm et al., (2004). For more information on the Sweeney Water Treatment Plant, please refer to Kennedy et al. (2004).

Introduction

Sweeney Water Treatment Plant (SWTP) is owned and operated by the City of Wilmington, NC. SWTP uses the Cape Fear River water as its source water, which has high organic content, high color, and low turbidity. The source water also contains iron and manganese that can cause aesthetic issues in the finished water. A summary of the source water quality as received at the SWTP is provided in Exhibit B.23.

1
2
3

Exhibit B.23 Cape Fear River Water Quality
(as received at the SWTP)

Water Quality Parameter (Unit)	Average	Minimum	Maximum
TOC (mg/L)	5.6	4.8	8.3
DOC (mg/L)	5.4	4.6	7.6
Filtered UV-254 Abs. (cm^{-1})	0.218	0.123	0.337
Specific ultraviolet absorbance (SUVA) (L/(mg-m))	4.0	2.7	4.4
Color (PCU)	46	25	76
Alkalinity (mg/L as $CaCO_3$)	25	16	30
pH	6.5	5.8	6.8
Turbidity (NTU)	16	3.5	73
Temperature (^{o}C)	20	11	28

4   Source: Adapted from Najm, et al., 2004
5   Note: Data collected between Oct. 2001 - July 2002
6
7   The treatment train for the SWTP is shown schematically in Exhibit B.24 below. The
8   capacity of the SWTP is 25 MGD, and consists of the following two treatment trains:
9
10   **South Plant (15 MGD)**
11   • coagulation
12   • flocculation
13   • sedimentation train
14   • intermediate ozonation
15   • dual-media GAC/sand filtration
16   **North Plant (10 MGD)**
17   • coagulation
18   • high rate clarification (SuperPulsator)
19   • intermediate ozonation
20   • dual-media GAC/sand filtration
21
22   Source water first undergoes pre-ozonation and is then split between the North and South
23   Plants, where the alkalinity is raised by adding caustic and/or lime. During the rapid mix step of
24   each treatment train, alum and cationic polymer are added. Primary disinfection requirements of
25   0.5-log *Giardia* removal and 2-log virus inactivation are satisfied via the intermediate ozonation
26   step. After undergoing filtration, the treated waters from the South Plant and North Plant are

1   joined and caustic and/or lime, chlorine, phosphate, and fluoride are added to the combined filter
2   effluent (CFE) before the water enters the clearwell. Finally, the effluent of the SWTP's
3   clearwell receives additional chlorination prior to entering the distribution system.
4
5
6   **Exhibit B.24 Schematic of SWTP**
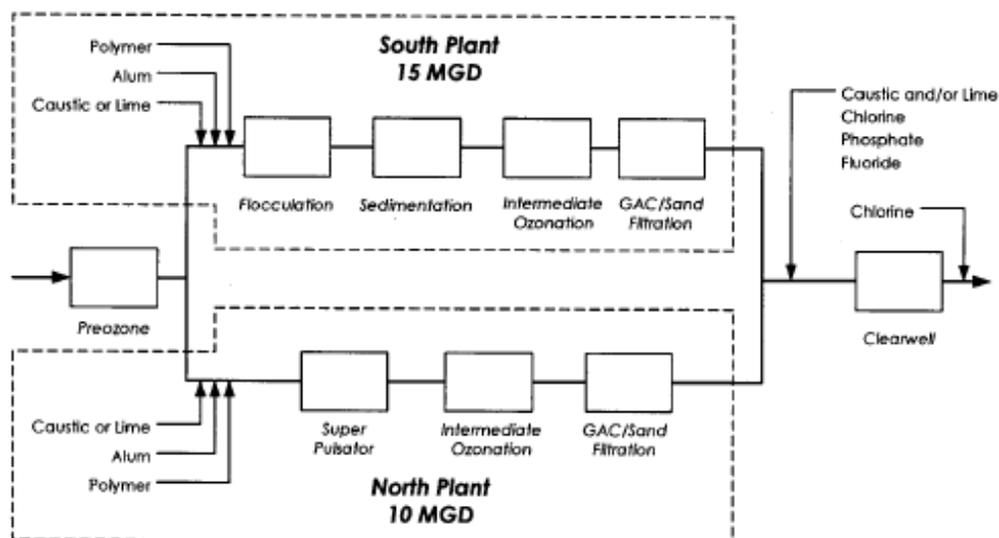
7   Source: Najm, et al., 2004
8
9
10   **Simultaneous Compliance Issue Faced by the Utility**
11
12   The City of Wilmington upgraded its facility for the following reasons:
13
14   •   to better accommodate future population growth,
15   •   to comply with LT2ESWTR regulations by providing *Cryptosporidium* inactivation,
16   and
17   •   to improve aesthetics and customer confidence.
18
19   Application of ozone also lowers the formation of TTHM and HAA5. However,
20   ozonation could lead to an increase in the AOC levels in the finished water, resulting in potential
21   microbial regrowth in the distribution system and non-compliance with the TCR. Biofiltration
22   was used to remove AOC before the water entered the distribution system.
23

Steps Taken by the Utility

Changes made to the original treatment train of the SWTP are outlined below.

- The North Plant (10 MGD facility) was constructed to be operated simultaneously with the existing South Plant (15 MGD).
- An ozone generation and dissolution facility was constructed.
- New pretreatment facilities were built for coagulation.
- 12 sand/anthracite filters were converted to biofilters by the use of deep bed dual media with gravel support and GAC.
- A SCADA system to monitor/control all processes and equipment in the facility was installed.

Ozonation and biological filtration began at the SWTP in March, 1998. Details of the two processes are provided below.

Ozonation Details

SWTP has two application points for ozone. First, in pre-ozonation, ozone is applied prior to coagulation, at doses between 3-7 mg/L. In intermediate ozonation, ozone is applied again to settled water at doses between 0.75 - 4.0 mg/L before the water undergoes biological filtration. The ozonation system at the SWTP uses a maximum of 1380 lbs ozone/day.

Biofiltration Details

Specifications for the four new biological filters in the North Plant are as follows:

- Support Gravel - 3"
- Silica Sand - 15"
- GAC - 48"

Specifications for the 12 existing filters in the South Plant which were converted to biological filtration are as follows:

- Support Gravel - 12"
- Silica Sand - 6"
- GAC - 21"

Finished water from the SWTP's storage reservoir is used to backwash the biological filters at both the North and South Plants. At the North Plant, the filters undergo air scouring prior to backwash, and at the South Plant, the filters use surface sweeps prior to backwash.

Results of the Steps Taken

After the upgrades made at the SWTP, the following water quality improvements have been observed.

- TOC reduction from raw water to settled water has been observed, and additional TOC reduction has been observed as result of the biological filtration. Finished water TOC levels have been reduced to 2.0 - 2.5 mg/L.

- TTHM levels have decreased to 60 µg/L (typical level).

- HAA5 levels have decreased from 48.5 µg/L (based on 1997 values) to 21.37 µg/L (based on 1999 values).

- Iron levels have been reduced from 0.9 mg/L (maximum level in source water) to less than 0.020 mg/L (finished water).

- Manganese levels have been reduced from 0.06 - 4.0 mg/L (range of typical to maximum levels in source water) to less than 0.01 mg/L (finished water).

Implementation and Operational Issues Faced by the Utility

The SWTP switched from disinfection with chlorine/chlorine dioxide to ozone. Although no specific issues were described for the SWTP, the following general issues are relevant to switching to disinfection with ozone.

- Increased costs (due to liquid oxygen, electricity, and higher O&M costs).
- Use of ozone requires a higher level of technical skill from the operators; therefore, increased training may be required.
- Since ozonation could lead to an increase in the AOC levels in the finished water, biofiltration should be implemented to remove the additional AOC.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21   This page intentionally left blank.

1   **Case Study #12**
2   **Ultraviolet Disinfection**
3   **Poughkeepsie Water Treatment Facility**
4   **Poughkeepsie, New York**
5
6
7   This case study provides an example of a water system that installed ultraviolet light
8   (UV) to meet DBP requirements while maintaining compliance with SWTR and IESWTR
9   requirements. By switching to UV, the system also facilitated compliance with the LT2ESWTR
10   requirements for *Cryptosporidium* inactivation.
11
12   The information for this case study comes from interviews with water treatment plant
13   staff (Alstadt 2005, Lill 2005) and from the plant's Web site at http://www.pokwater.com.
14   Readers are also encouraged to refer to the *Draft Ultraviolet Light Disinfection Guidance*
15   *Manual* (U.S. EPA 2003b) for information on UV sensor calibration procedures and practices.
16
17   **Introduction**
18
19   Poughkeepsie's Water Treatment Facility (PWTF) is a surface water treatment plant
20   located in Poughkeepsie, New York. The plant uses the Hudson River as a source and has a
21   capacity of 16 MGD. In March 2002 the system began a series of improvements to the plant to
22   increase its rated capacity, ensure continued compliance with existing regulations, and prepare
23   for expected future regulations. In the second quarter of 2003 (May 1 through July 31) the
24   PWTF incurred a violation for exceeding the MCL for HAA5. The system has been in
25   compliance with the MCLs for both HAA5 and TTHM since that date and is completing
26   modifications, including installing UV, to prevent another exceedance.
27
28   PWTF is a conventional surface water treatment plant with rapid mix, followed by three
29   parallel trains, each with a solids contact tank and sedimentation followed by filtration. The
30   plant has a total of six filters. An equalization basin succeeds the filters with orthophosphoric
31   acid added in the first half and sodium hydroxide added in the second half. Chlorine is added in
32   the sedimentation basins and again just before the water leaves the treatment plant to maintain a
33   residual in the distribution system.
34
35   **Simultaneous Compliance Issues Faced by the Utility**
36
37   The primary issue faced by the system was the need to reduce DBPs. However, in doing
38   so, the system needed to ensure that it could maintain a high enough CT to ensure compliance
39   with the requirements for *Giardia* and viruses. In addition, the LT2ESWTR was expected to
40   contain new requirements for *Cryptosporidium* inactivation. The system needed to consider how
41   any modifications made to address DBPs could impact the system's ability to meet these other
42   requirements.

1
2   **Steps Taken by the Utility**
3
4   In order to reduce DBPs, the system proposed moving the point of disinfection from the
5   sedimentation basins to just prior to the filters, after more DBP precursors have been removed.
6   However, in doing so, the system would lose some disinfection contact time. In order to
7   maintain the necessary CT, the system needed to add an additional contact basin after the filters.
8   Due to space limitations, constructing a contact basin large enough to maintain CT was not
9   feasible. Therefore, the system chose to install UV after each filter to provide additional CT and
10 meet space requirements. In addition, UV does not produce any DBPs, so installing UV rather
11 than additional chlorine contact time after the filters would further reduce the system's TTHM
12 and HAA5 levels. The UV installation and all associated modifications have been completed.
13
14   An additional benefit of installing UV at the PWTF is that UV has been shown to be an
15 effective technology for inactivating *Cryptosporidium* at a low dose. The use of UV at PWTF
16 should enable the system to meet the *Cryptosporidium* inactivation requirements under the
17 LT2ESWTR.
18
19   PWTF is now planning to switch from chlorine to chloramines for secondary disinfection
20 to further reduce DBPs in the distribution system. The system will continue to use chlorine and
21 UV as primary disinfectants, but will begin adding ammonia after the equalization basin to form
22 chloramines. The system expects to begin using chloramines in 2006 after a new flushing
23 program has been implemented.
24
25 **Expected Results of the Steps Taken**
26
27   Bench-scale pilot testing indicated that installing UV would reduce TTHM and HAA5 by
28 20 percent. Pilot testing also showed that addition of chloramines will reduce DBPs by another
29 80 percent. The UV installation is expected to provide 3-log inactivation of *Giardia* and
30 *Cryptosporidium*, which will ensure that the system maintains compliance with the Giardia
31 inactivation requirements under the IESWTR. In addition, the system should be able to meet the
32 requirements for *Cryptosporidium* under the LT2ESWTR. Because UV is less effective against
33 some kinds of viruses, the system expects that it will need to achieve 1 log of virus inactivation
34 through chlorination after the UV units. The system will meet this requirement with the existing
35 equalization basin.
36
37 **Implementation and Operational Issues Faced by the Utility**
38
39   One of the biggest issues for the PWTF staff during the modifications was learning to
40 operate and maintain the UV system. PWTF found that operating a UV system is very different
41 from operating a chemical disinfection system. It is a fairly simple process to determine when a
42 chemical disinfection system is operating properly because the residual can be easily measured
43 with a grab sample. Determining how effectively a UV unit is working is much more complex

because there is no measurable residual in the water. In order to determine the UV dose received by organisms in the water, the operator needs to know the intensity delivered by the UV bulbs and the transmittance of the water. The UV reactor contains an array of sensors that are used to determine the intensity and the readings among the sensors can vary significantly, making it difficult to determine which are correct. PWTF staff had problems with many of the intensity sensors in their UV chambers and had to have them replaced. They also had problems with the transmittance meter. These problems had not been resolved as of Fall 2005.

Obtaining appropriate training was also an issue for the system. Although the manufacturer provided some training, the water treatment plant staff had not yet worked with the UV system and were unable to communicate specific training needs to the manufacturer. Therefore, the plant staff found that many operational and maintenance issues arose during installation and testing that were not addressed during training.

Programming the UV system and integrating it into plant controls was difficult. The water treatment plant would have to be shut down if the UV system failed and the control system would need to be programmed to do so. In addition, the UV units require 10 minutes to cool down before shutdown to avoid damage to the UV units. Therefore, PWTF had to install a UPS to hold the power for the UV units for 10 minutes in the event of a power failure. Trying to consider all possible scenarios and how to react to and program them was a complicated process.

Large UV systems require a significant amount of power, particularly at high doses. The UV units at PWTF have all been successfully started up and the system is receiving one (1) log inactivation credit for the UV although the primary disinfectant application point has not yet been moved. With all UV units running, PWTF observed a 20 percent increase in power utilization, which significantly increased the plant's power costs. The new UV system also led to increased maintenance time and costs. The UV system has many components, such as sensors and bulbs, which require periodic replacement. In addition, the monitoring equipment must be calibrated regularly.

Lessons Learned From this Case Study

- UV disinfection is very different from chemical disinfection. It is important that operators undergo training and have continued access to knowledgeable representatives from the manufacturer during installation and start-up of this technology to allow them to become comfortable with the new instrumentation and controls.

- UV is an effective technology both for reducing DBPs and inactivating *Giardia* and *Cryptosporidium*. However, it also consumes much more electricity than chlorination or chloramination. Therefore, it is important to consider the availability of electricity and the financial impact of increased power usage before installing UV.

1   **References**
2
3   Alstadt, R. 2005. Personal Communication.
4
5   Lill, P. 2005. Personal Communication.

Case Study #13
Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection
Gulf Coast Water Authority
Texas City, TX

This case study provides an example of a water treatment plant with high influent TOC, high bromide, warm water temperatures, and long residence times in the distribution system that converted to chlorine dioxide as a primary disinfectant and chloramines as a secondary disinfect to reduce the formation of chlorinated DBPs.

The information for this case study was obtained primarily from Krasner et al. (2003). Readers should refer to that text for more detailed information.

Introduction

The Gulf Coast Water Authority (GCWA), which has been operating since 1981, operates the Thomas S. Mackey WTP from which treated water is wholesaled to seven municipalities between Houston and Galveston, TX. All of the systems served by GCWA conduct their own distribution system monitoring for regulatory compliance. Approximately 92,000 people are served by the GCWA in the seven municipalities. Additionally, raw water is pumped to industry and treated water is provided to the City of Houston via pipeline between Houston and Galveston.

The current rated capacity of the Thomas S. Mackey WTP is 25 MGD, with approximate average and maximum flows of 12 and 20 MGD, respectively.

GCWA uses the Brazos River as their source water, which has moderate to high levels of TOC, hardness, alkalinity, and bromide.

A summary of the influent water quality to the GCWA is provided in Exhibit B.25.

1
2   **Exhibit B.25 Water Quality at GCWA**
3

Water Quality Parameter	Influent Concentration
Turbidity (NTU)	~ 35 (median)
Hardness (mg/L as CaCO$_3$)	190 (median)
pH	8.25 (median)
Alkalinity (mg/L as CaCO$_3$)	135 (median)
TOC (mg/L)	4.7 (median)
Bromide (mg/L)	up to 0.3

4
5
6 **The Original Treatment Process at the Gulf Coast Water Authority**
7
8   Before treatment changes were made at the Thomas S. Mackey WTP, free chlorine was
9 used as a primary disinfectant. The treatment train consisted of the following:
10
11   •   raw water pumping
12   •   chemical addition (including lime softening)
13   •   upflow solids contact/clarification
14   •   recarbonation
15   •   filtration
16   •   disinfection (with free chlorine)
17   •   finished water pumping
18
19   The Brazos River has moderate to high concentrations of TOC, as well as high bromide
20 concentrations. The Thomas S. Mackey WTP was using chlorine as a disinfectant; therefore,
21 GCWA was facing the challenge of controlling formation of chlorinated and brominated DBPs.
22 Under these conditions, TTHM formation was ranging up to 350 μg/L, and TTHM formation
23 potential (TTHMFP) concentrations were ranging between 800 and 1000 μg/L. These concerns
24 were the main reasons that GCWA changed their disinfection strategy from chlorine to chlorine
25 dioxide.
26
27 **Simultaneous Compliance Issues Faced by the Utility**
28
29   Disinfection with chlorine dioxide raised the following compliance issues for GCWA:
30
31   •   Ensuring that the system was in compliance with SWTR and IESWTR under all
32   operating conditions

1   • Ensuring that the Stage 1 DBPR TTHM MCL of 80 µg/L and HAA5 MCL of 60
2   µg/L were not exceeded
3   • Ensuring that the Stage 1 DBPR chlorine dioxide MRDL of 0.8 mg/L and the chlorite
4   MCL of 1.0 mg/L were not exceeded
5
6   Note, at the time of the treatment train modifications, the plant was initially operating to
7   comply with a TTHM MCL of 100 µg/L and limiting the use of chlorine dioxide to make sure
8   the sum of chlorine dioxide, chlorite, and chlorate did not exceed 1 mg/L.
9
10 **Steps Taken by the Utility**
11
12   GCWA conducted eight phases of research before a final decision was made to use
13 chlorine dioxide as both a primary and secondary disinfectant. Exhibit B.26 show the various
14 disinfection strategies implemented at GCWA during the eight phases.
15
16   **Exhibit B.26 Disinfection Strategies implemented at GCWA**
17

Phase	Dates	Primary Disinfectant	Secondary Disinfectant
1	Prior to 11/83	Chlorine	chlorine
2	11/83	Chloramines	chloramines
3	12/83 - 4/84	Chloramines	chlorine[4]
4	5/84 - 2/85	chlorine dioxide	chlorine
5	3/85 - 4/85	chlorine dioxide	chlorine dioxide
6	5/85 - 11/85	chlorine dioxide	chlorine dioxide/chlorine
7	12/85 - SWTR[1]	chlorine dioxide	chlorine dioxide/ chloramines
8	SWTR - 2003	chlorine dioxide[2]/chlorine dioxide[3]	chloramines

18 Source: Adapted from Krasner et al., 2003.
19 Notes:
20 [1] Disinfection scheme changed after SWTR promulgation
21 [2] Chlorine dioxide used intermittently as a pre-oxidant in raw water
22 [3] Chlorine dioxide used as primary disinfectant following filtration
23 [4] Breakpoint chlorination used to achieve free chlorine residual in distribution system
24
25
26   As shown in Exhibit B.26, the eight phases span more than 20 years. Following
27 promulgation of SWTR, chlorine dioxide was used as a primary disinfectant, which was applied
28 after filtration. Chloramines were used for secondary disinfection. Additionally, chlorine
29 dioxide was also intermittently used as pre-oxidant, which was applied to the raw water.

1
2   A process schematic of the treatment train at the Thomas S. Mackey WTP after changes
3   were made is provided in Exhibit B.27.

1   **Exhibit B.27 Schematic of Thomas S. Mackey WTP Treatment TrainAfter Changes**
2   **Were Made**
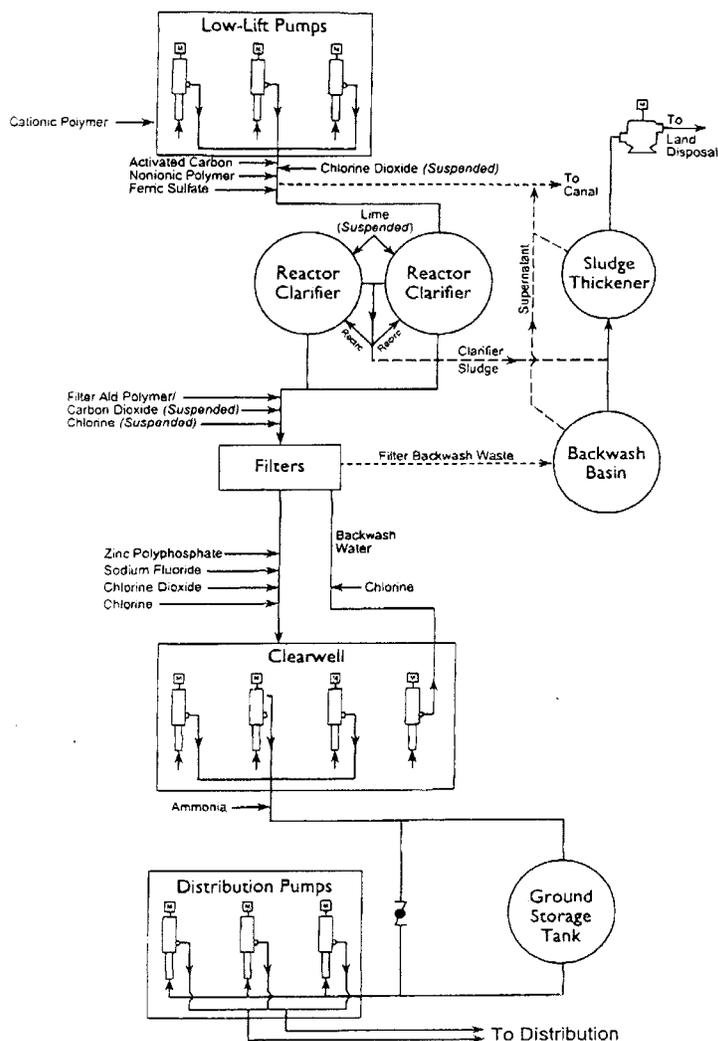
45   Source: Krasner et al., 2003.

47   **Results of the Steps Taken**

49   During the disinfection scheme used in phase 8, TTHM concentrations decreased
50   significantly from above 300 µg/L when free chlorine was used as the disinfectant. Disinfection
51   with chlorine dioxide, followed by residual disinfection with chloramines, decreased TTHM
52   concentrations in the GCWA system by approximately 80 percent, to 50 - 70 µg/L.

1   Stage 1 DBPR set a chlorine dioxide MRDL of 0.8 mg/L and a chlorite MCL of 1.0
2   mg/L. GCWA is in compliance with these requirements. GCWA applies a chlorine dioxide
3   dose of 0.75 mg/L and, as shown in Exhibit B.28, the chlorite concentration in the treated water
4   is 0.5 mg/L. However, the chlorine dioxide dose applied is not high enough to obtain any CT log
5   removal credit under LT2ESWTR.
6
7   The GCWA treated water quality after modifications were made to disinfection is
8   summarized in Exhibit B.28.
9
10   **Exhibit B.28 Treated Water Quality at GCWA**
11

Water Quality Parameter	Concentration
Turbidity (NTU)	0.14 (median)
Hardness (mg/L as CaCO$_3$)	185 (median)
pH	7.63 (median)
Alkalinity (mg/L as CaCO$_3$)	120 (median)
TOC (mg/L)	2.9 (median)
Bromide (mg/L)	0.11 (median)
TTHM (mg/L) Finished water (clearwell effluent) Customers' distribution system	36 - 58 50 - 70, (RAA = 55)
Chlorite (mg/L)	0.5 (median)
Chlorate (mg/L)	0.18 (median)

12   Note: Based on data collected between January 1996 - November 1997. Partial lime softening was discontinued in
13   1994.
14
15

Implementation and Operational Issues Faced by the Utility

Because chlorine dioxide was a new technology at the time GCWA was considering switching disinfectants, they were faced with some technical questions and challenges in the implementation of chlorine dioxide as their primary disinfectant. Most of the technical issues concerned distribution system water quality, and therefore there was need for a full-scale plant study. The main technical issues faced by GCWA are summarized below:

- Effectiveness of disinfection with chlorine dioxide
- Microbial side effects in distribution system
- Production of chlorite as a byproduct of chlorine dioxide generation
- Taste and odor issues related to disinfection with chlorine dioxide

Lessons Learned From this Case Study

- Use of chlorine dioxide can help a system comply with TTHM and HAA5 MCLs.

- Systems may have trouble providing sufficient *Cryptosporidium* inactivation to satisfy LT2ESWTR toolbox requirements and still meet the chlorine dioxide MRDL and chlorite MCL.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

This page intentionally left blank.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33

Case Study #14
Chlorine Dioxide for Primary Disinfection and Chloramines for Residual Disinfection
Village of Waterloo Water Treatment Plant
Waterloo, New York

This case study provides an example of a small surface water system that successfully converted from using chlorine as its primary and residual disinfectant to using chlorine dioxide for primary disinfection and chloramines for residual disinfection. By switching disinfectants, the Village of Waterloo improved its ability to comply with Stage 1 DBPR and Stage 2 DBPR requirements, added protection against *Cryptosporidium*, and improved the system's ability to maintain a disinfectant residual throughout its distribution system. The narrative for this case study borrows from Gell and Bromka (2003). Readers should refer to this paper for more information about the changes made to Waterloo's system.

Introduction

The Village of Waterloo operates a diatomaceous earth (DE) filtration plant that draws water from Seneca Lake in central New York. The original treatment plant design provides a nominal capacity of 2 million gallons per day (MGD), but the system plans to expand its service to neighboring areas. The system currently serves fewer than 10,000 people, but covers a large geographical area.

The DE filtration produces a low turbidity finished water (usually <0.2 NTU) but does not significantly reduce concentrations of DBP precursors. When chlorine was used, DBPs leaving the plant were generally low but increased to levels close to or above the TTHM MCL. The high DBP levels resulted because the distribution system is sufficiently large and retention time sufficiently long that chlorine, NOM, and bromide in the water had several days to react with each other and form high TTHM concentrations.

A summary of Seneca Lake raw water quality is provided in Exhibit B.29.

1
2   **Exhibit B.29 Seneca Lake Raw Water Quality**
3
4

Water Quality Parameter	Average	Observed Range
pH	8.1	7.7 - 8.3
total alkalinity (mg/L as $CaCO_3$)	84	69 - 119
total hardness (mg/L as $CaCO_3$)	145	107 - 158
bromide (mg Br^-/L)	0.32	0.28 - 0.50
turbidity (NTU)	0.63	0.21 - 2.21
TOC (mg C/L)	2.74	2.1 - 4.0
DOC (mg C/L)	2.51	1.7 - 3.2
SUVA (L/mg-m)	1.20	0.63 - 3.13
chlorine demand[1] (mg Cl_2/L)	1.24	0.35 - 3.50

5   Adapted from Gell, R. and Bromka, 2003.
6   [1] Timeframe for the chlorine demand is 1.5 to 2 hours, depending on how much water is being pumped by the
7   system.
8
9

10   Moderate bromide concentrations in the raw water were causing predominantly
11   brominated THMs to be formed in the finished water. A 1998 survey of distribution system
12   samples showed an average TTHM concentration of 79 μg/L and an average HAA5
13   concentration of 21 μg/L. TTHM concentrations ranged from 48 to 150 μg/L, with
14   approximately 75 percent of the TTHM being brominated compounds.
15
16   At the same time when the Waterloo system was considering treatment modifications to
17   improve water quality, the system was receiving requests from neighboring areas to expand its
18   service area. As a result, modifications made at the treatment plant included upgrades to
19   increase capacity as well as improve water quality.
20
21   **The Original Treatment Process at the Waterloo WTP**
22
23   The Village had added potassium permanganate consistently, and PAC/permanganate
24   seasonally, to control zebra mussel growth and taste and odor problems. These were fairly
25   effective at controlling seasonal taste and odor problems, but the Village operators were
26   interested in improving taste and odor treatment for more consistent control.
27

1   Chlorine had previously been added after the DE filters and before water entered the
2 clearwell in order to achieve sufficient *Giardia* and virus CT. Chlorine was added again at
3 booster stations in order to maintain a sufficient disinfectant residual throughout
4 the distribution system.
5
6 **Simultaneous Compliance Issues Faced by the Utility**
7
8   The Village of Waterloo faced problems complying with both the Stage 1 D/DBPR and
9 the Stage 2 DBPR due to high TTHM concentrations in its distribution system. It was having
10 trouble maintaining a disinfectant residual throughout the distribution system, which is a
11 requirement of the SWTR.
12
13   At the same time that the Stage 1 DBPR requirements were introduced, the IESWTR and
14 the LT1ESWTR introduced requirements for the removal of *Cryptosporidium*. Although DE
15 filtration is not effective at removing DBP precursors, the Village of Waterloo wanted to keep its
16 DE filters in use because of their simplicity and performance for *Cryptosporidium* removal. The
17 Village has been monitoring their raw water for *Cryptosporidium* for several years, and no
18 oocysts have been detected.
19
20 **Steps Taken by the Utility**
21
22   A pilot study helped the Village realize that installing treatment to remove DBP
23 precursors would not be efficient, because of the low SUVA concentrations in Seneca Lake's
24 water. Since the system uses DE for its filtration step, enhanced coagulation would have
25 required significant modifications to the current filtration process. Moreover, the Waterloo
26 treatment plant's lakefront location limited options for the disposal of waste streams that would
27 have been generated by many of the DBP precursor removal options.
28
29   Simulated distribution system testing showed that TTHM and HAA5 concentrations
30 could be lowered significantly if the system changed its residual disinfectant from chlorine to
31 chloramines. This discovery enabled the system to keep its existing DE filtration process by
32 opting for an alternative disinfection strategy.
33
34   In addition, by changing its primary disinfectant from chlorine to chlorine dioxide, the
35 Village could simplify its operations by eliminating the use of potassium permanganate for zebra
36 mussel and taste and odor control. Chlorine dioxide is now injected at the intake structure.
37 Furthermore, changing primary disinfectant from chlorine to chlorine dioxide has enabled a
38 smaller clearwell expansion, which has reduced the amount of expensive lakefront real estate
39 needed by the treatment plant.
40
41   Chlorine dioxide is added to the intake and maintains a residual throughout the clearwell.
42 Anhydrous ammonia is added immediately after the clearwell into the discharge pipe before
43 water is pumped into the distribution system. A few yards downstream of the ammonia addition

1 point, chlorine gas is injected. Bench scale tests determined the optimum ammonia and chlorine
2 dosages to maintain a total chlorine residual of 2.0 mg/L over several days.
3
4   Before converting from free chlorine to chloramines, the Village, with assistance from its
5 consultants, conducted a thorough and successful public notification campaign to inform users of
6 the potential adverse impact of chloramines consumption (primarily for dialysis patients and fish
7 owners). The Village hosted public meetings, placed newspaper articles, and issued notifications
8 that provided the important information.
9
10 **Results of the Steps Taken**
11
12   The reductions in TTHM and HAA5 concentrations after the system switched to chlorine
13 dioxide and chloramines exceeded the Water Manager's expectations. In 2002, THM levels
14 were mostly below their detection levels, with one TTHM measurement of 2.1 μg/L in August at
15 the farthest sampling location. HAA5 concentrations in 2002 averaged 8 μg/L. The total
16 chlorine residual has been maintained throughout the distribution system without the use of re-
17 chlorination stations.
18
19   The chlorine dioxide dosage ranges from 0.4 to 1.00 mg/L, depending on water
20 temperature. Distribution system chlorite concentrations range from 0.25 to 0.45 mg/L.
21
22   The Village has not experienced any uncontrollable re-growth episodes, but uses a
23 carefully monitored program to address the potential for nitrification and biological re-growth.
24 As part of this effort, the Village adheres to the following guidelines:
25
26   ◆   Maintain a high chlorine to ammonia weight ratio (5:1) at the time when the
27   chloramines are formed.
28   ◆   Maintain a finished water total chlorine residual of 2 mg/L and a residual of at least
29   1.0 mg/L throughout the distribution system.
30   ◆   Take advantage of the possibility that chlorite, a byproduct of chlorine dioxide
31   disinfection, may be toxic to nitrifying bacteria.
32   ◆   Monitor monthly for HPC, nitrite, chlorite, free and total ammonia at each storage
33   tank and at key points in the distribution system.
34   ◆   Routinely check the percentage of monochloramine in the total chlorine present. Aim
35   to have at least 95 percent monochloramine leaving the treatment plant.
36
37   Since switching disinfectants, the Village has observed two occasions when HPC
38 numbers increased, and traced the cause of these events to stagnation in a remote storage tank.
39 Sodium hypochlorite was added to the tank and HPC levels returned to normal. Plans are being
40 developed to improve mixing in the tanks.
41
42   The Water Director believes that previously bothersome taste and odor problems are
43 being controlled more effectively by using chlorine dioxide. He also believes that the use of

1   chloramines following chlorine dioxide has prevented the development of nuisance odors
2   associated with chlorine dioxide in households (see Hoehn *et al.*, 1990).
3
4   **Implementation and Operational Issues Faced by the Utility**
5
6   The Village encountered an operational problem when it first converted to chloramines.
7   Ammonia reacts with calcium and magnesium hardness in the water and produces a scale, even
8   when hardness values are as low as 35 mg/L as CaCO$_3$. As a result, scaling was clogging the
9   injector throat of the ammonia feed system. Since a water softening unit was installed to treat
10   the water that is used for injection, the ammonia feed system has functioned reliably.
11
12   The Village has a service contract with the company that provided the chlorine dioxide
13   equipment to supply sodium chlorite and monitor and verify the performance of the generator.
14   This contract has provided the Village with sufficient time to educate its staff on proper
15   equipment operation.
16
17   **Further Reading**
18
19   Readers who are interested in learning more about the Village of Waterloo system should refer to
20   the following paper:
21
22   Gell, Richard and Bromka, James. 2003. Successful Application of Chloramines to Manage
23   Disinfection By-Products. *New York State Section AWWA*. September 2003. Published by
24   O'Brien and Gere.

1   This page intentionally left blank.

1 **Appendix C**
2 **Guidelines for Evaluating Potential Impacts of Treatment Changes on**
3 **Distribution Systems**

1   This page intentionally left blank.
2

1   **Appendix C Guidelines for Evaluating Potential Impacts of Treatment**
2   **Changes on Distribution Systems**
3
4   This appendix is designed to accompany the guidance manual and act as a tool for examining
5   issues that might arise in the distribution system as a result of changes made during treatment.
6   The table below lists treatment changes that could potentially impact the distribution system and
7   page numbers in this appendix where the potential impacts of particular treatment changes are
8   discussed. A list of references is also included for each distribution system impact.
9

Treatment Change	See Appendix Page
Modifying pH	C-2
Change in finished water alkalinity	C-6
Change in finished water oxidation/reduction potential	C-9
Switching from chlorine to chloramines	C-10
Switching coagulant	C-14
Modifying chlorine dose with warmer water temperatures	C-16
Adding/discontinuing softening	C-17
Adding ozone	C-21
Adding chlorine dioxide	C-24
Enhanced coagulation	C-27
Installing nanofiltration	C-30
Installing granular activated carbon	C-33
Installing ozone without subsequent biological filtration	C-34

1   **MODIFYING pH**
2
3   The following impacts to your distribution system may result from modifying pH:
4
5   •   Increased lead and copper in tap water
6   •   Change/disruption of scale
7   •   Colored water
8   •   High iron
9   •   Increased heterotrophic bacteria
10   •   Nitrite/nitrate formation
11   •   Change in DBP concentration/composition
12
13
14   References, along with brief descriptions of treatment impacts, are provided below. Refer to
15   Section 3.4 for additional information on modifying pH during chlorination.
16
17

Increased lead and copper in tap water
Description As the pH of water decreases, the corrosion potential of the water increases. Therefore, a significant decrease in finished water pH may result in a significant increase in corrosion of distribution system pipes, resulting in increased concentrations of metals such as iron, copper, and lead in the water. In addition, if the pH of the water is too low, protective scales may be disrupted or unable to form on pipe surfaces.
Further Reading • U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999. • U.S. EPA. 2000c. Lead and Copper Rule: Summary of Revisions. Office of Water. EPA 815-R-99-020. • U.S. EPA. 2003h. Revised Guidance Manual for Selecting Lead and Copper Control Strategies. Office of Water. EPA 816-R-03-001. March, 2003. • AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725. • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

18

Change/disruption of scale
Description When water is supersaturated with calcium carbonate, the calcium carbonate can precipitate in the distribution system and form a coating on pipes that protects against corrosion. The pH of the water plays a major role in the solubility of calcium carbonate.   If the pH in the distribution system is too low, calcium carbonate becomes undersaturated, causing scales to change or become dislodged. Scales can also form in the distribution system from corrosion byproducts. Because corrosion (and subsequently formation of these scales) is partially dependent on pH, these scales can also be disrupted by changes in pH.
Further Reading   - AWWA. 1999c. Water Quality and Treatment: A Handbook of Community Water Supplies. Fifth Edition. Letterman, R.D. (editor). McGraw-Hill. 1,233 pp.   - U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.   - AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.   - Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.   - Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Colored water
Description A decrease in pH can lead to increased corrosion and increased solubility of inorganics, which may result in increased iron and copper levels. A change in pH can also cause disruption of scales. Increased iron levels and disruption of scale containing iron corrosion byproducts can cause red water. Increased copper levels can cause blue or green water.
Further Reading   - U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.   - White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.   - Connell, G. 1996. The Chlorination/Chloramination Handbook. AWWA. Denver, CO. 174 pp.   - Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.   - AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.   - Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.   - Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.

High iron
Description A decrease in pH can lead to increased corrosion and increased solubility of inorganics, which may result in increased iron levels when iron pipe is used. A change in pH can also cause disruption of scales. If the scales contain corrosion byproducts, the iron levels in the water can be further increased.
Further Reading   - U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.   - White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.   - Connell, G. 1996. The Chlorination/Chloramination Handbook. AWWA. Denver, CO. 174 pp.   - Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Increased heterotrophic bacteria
Description Films and scales can build up on distribution system pipes and may contain microorganisms as well as inorganic contaminants and TOC. If the pH fluctuates below 7.0 in the distribution system, these scales may become dislodged. This would allow the release of the trapped microorganisms into the distribution system, thereby increasing their numbers in the water.
Further Reading   - White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.   - Connell, G. 1996. The Chlorination/Chloramination Handbook. AWWA. Denver, CO. 174 pp.   - Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.   - AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.   - Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.   - Lauer, William C. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.   - Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.   - Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Nitrite/nitrate formation
Description The optimum pH for nitrification to occur is between 7.5 and 8.5. If systems using chloramines make changes resulting in a finished water pH in this range, these systems may have problems with nitrification in the distribution system, causing increased levels of nitrite and nitrate.
Further Reading • Harrington, G.W., D.R. Noguera, C.C. Bone, A.I. Kandou, P.S. Oldenburg, J.M. Regan, and D. Van Hoven. 2003. Ammonia from Chloramine Decay: Effects on Distribution System Nitrification. AWWARF Report 90949. Project #553. • Kirmeyer, G.J. et al. 2004. Update of Optimizing Chloramine Treatment. AWWARF Report 90993. Project #2760. • Kirmeyer, G.J. et al. 1995. Nitrification Occurrence and Control in Chloraminated Water Systems. AWWARF Report 90669. Project #710. • White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY. • Cowman, G.A., and P.C. Singer. 1994. Effect of Bromide Ion on Haloacetic Acid Speciation Resulting from Chlorination and Chloramination of Humic Extracts. Conference proceedings, AWWA Annual Conference, New York, NY. • Connell, G. 1996. The Chlorination/Chloramination Handbook. AWWA. Denver, CO. 174 pp. • U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014. • Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp. • AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp. • Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357. • Lauer, William C. 2005. Water Quality in the Distribution System. AWWA. Denver, CO. • Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO. • Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Change in DBP concentration/composition
Description Reducing the pH of the water may allow systems to use a lower chlorine concentration for disinfection, leading to less DBP formation. Since TTHMs generally show lower formation at lower pH, reducing the pH can also lead to lower TTHM levels. However, HAA5s generally show higher formation at lower pH, so the HAA5 levels may increase.
Further Reading   - White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.   - Connell, G. 1996. The Chlorination/Chloramination Handbook. AWWA. Denver, CO. 174 pp.   - U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.   - Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp   - AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.   - Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.   - Lauer, William C. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.   - Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.   - Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

1

1   **CHANGE IN FINISHED WATER ALKALINITY**
2
3   The following impacts to your distribution system may result from changes in finished water
4   alkalinity:
5
6   • Increased lead and copper in tap water
7   • Change/disruption of scale
8   • Colored water
9   • High iron
10   • Pinhole leaks
11
12   The following reference can provide further information about how to address most of these
13   impacts. Additional references and brief descriptions are listed by impact in the table below.
14
15   • AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of
16   Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
17
18   Refer to Sections 3.4 and 3.7 for additional information on changes in finished water alkalinity.
19
20

Increased lead and copper in tap water
Description When alkalinity is removed, the carbonate system must re-equilibrate, resulting in the production of the hydrogen ion. This in turn results in a lowering of the pH of the water. In addition, as alkalinity decreases, the buffering capacity of the water decreases, allowing the pH of the water to change more easily during treatment processes. However, when the alkalinity and pH are high, lead corrosion can also increase as a result of increased lead solubility and lead complexation with carbonate (AWWA 1999d). Therefore, both increases and decreases in finished water alkalinity can increase lead levels in tap water. Copper levels can also increase because bicarbonate is extremely aggressive toward copper (AWWA 1999d).
Further Reading • AWWA. 1999c. Water Quality and Treatment: A Handbook of Community Water Supplies. Fifth Edition. Letterman, R.D. (editor). McGraw-Hill. 1,233 pp. • AWWA. 2004c. Draft. Managing Lead and Copper Rule Corrosion Control Practices to Avoid Unintended Consequences. • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Change/disruption of scale

Description

Alkalinity is a measure of the carbonate and bicarbonate in water. When calcium ions combine with carbonate in water it can precipitate out to form a protective coating on pipes in the distribution system. If the alkalinity in the water is subsequently reduced, some of the calcium carbonate may re-dissolve in the water, disrupting the protective scale on the pipes, which can lead to increased corrosion or release of scales and corrosion by-products. Lowered alkalinity can also lead to increased leaching from cement/mortar lined pipes. In addition, when alkalinity is reduces, the pH in the water can fluctuate more easily. Fluctuations in pH can in turn disrupt scales in the distribution system.

Further Reading

- AWWA. 1990. Water Quality and Treatment. F.W. Pontius (editor). McGraw-Hill, New York, NY.
- U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.
- Douglas, B.D., and D.T. Merrill. 1991. Control of Water Quality Deterioration Caused by Corrosion of Cement-Mortar Pipe Linings. AWWARF

Colored water

Description

A decrease in alkalinity can result in a lowering of the pH of the water. The buffering capacity of the water also decreases, allowing the pH of the water to change more easily during treatment processes and in the distribution system. Decreased pH can lead to increased corrosion of iron pipe. In addition, decreased alkalinity can cause disruption of protective pipe scales, which can lead to further corrosion. Corrosion byproducts in the water can cause colored water problems.

Further Reading

- AWWA. 1990. Water Quality and Treatment. F.W. Pontius (editor). McGraw-Hill, New York, NY.
- Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.
- AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.
- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.

High iron
Description A decrease in alkalinity can result in a lowering of the pH of the water. The buffering capacity of the water also decreases, allowing the pH of the water to change more easily during treatment processes. Decreased pH can lead to increased corrosion of pipes. In addition, decreased alkalinity can cause disruption of protective pipe scales, which can lead to further corrosion. If iron pipe is present in the distribution system, increased corrosion can lead to higher iron levels in the water.
Further Reading   - AWWA. 1990. Water Quality and Treatment. F.W. Pontius (editor). McGraw-Hill, New York, NY.   - Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.
Pinhole leaks
Description Changes in finished water alkalinity and resulting changes in pH can cause water to become more corrosive to copper piping, especially in the absence of corrosion inhibitors such as phosphate or NOM.
Further Reading   - Edwards, M., J.C. Rushing, S. Kvech, and S. Reiber. 2004. Assessing copper pinhole leaks in residential plumbing. Water Science and Technology. 49(2): 83-90.   - Edwards, M., J.F. Ferguson, S. Reiber. 1994. The Pitting Corrosion of Copper. Journal of American Water Works Association. 86(7): 74-91.

1

1   **CHANGE IN FINISHED WATER OXIDATION/REDUCTION POTENTIAL**
2
3   Oxidation/reduction (redox) potential is the ability of the water to oxidize or reduce compounds
4   it comes into contact with, and is measured electrochemically. The following impacts to your
5   distribution system may result from if a treatment change causes a change in finished water
6   oxidation/reduction potential:
7
8   •   Increased lead in tap water
9   •   Change/disruption of scale
10
11 The following references can provide further information about how to address both of these
12 impacts. Additional references and brief descriptions are listed by impact in the table below.
13
14   •   AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of
15   Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
16   •   Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control
17   in Distribution Systems. AWWARF. Denver, CO.
18
19 Refer to Section 5.1 for additional information on changes to finished water oxidation/reduction
20 potential.
21

22

Increased lead in tap water
Description Raising or lowering the oxidation/reduction potential can affect the redox state of any corrosion products existing in passivating layers in the distribution system. As the solubility of lead changes with its redox state, this can lead to solublization of lead and its release into tap water. Ammonia and nitrate can increase leaching of lead from materials such as brass.
Further Reading   •   AWWA. 2004d. Proceedings of Getting the Lead Out: Analysis & Treatment of Elevated Lead Levels in DC's Drinking Water. WQTC.
Change/disruption of scale
Description Changing the oxidation/reduction potential of the finished water will affect the oxidation/reduction equilibrium between the pipe surface and the water. Oxidation/reduction reactions may occur at the pipe surface to enable oxidation/reduction equilibrium to be achieved. If these reactions alter any passivating layers, dissolution and release of metals may occur.

Further Reading

- AWWA. 2004c. Draft. Managing Lead and Copper Rule Corrosion Control Practices to Avoid Unintended Consequences.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

1   **SWITCHING FROM CHLORINE TO CHLORAMINES**
2
3   The following impacts to your distribution system may result from switching from chlorine to
4   chloramines:
5
6   • Increased lead in tap water
7   • Change/disruption of scale
8   • Taste and odor
9   • Increased coliform bacteria
10   • Increased heterotrophic bacteria
11   • Nitrite/nitrate formation
12   • Change in DBP concentration/composition
13
14   The following references can provide further information about how to address most of these
15   impacts. Additional references and brief descriptions are listed by impact in the table below.
16
17   • Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second
18   Edition. AWWA. Denver, CO. 278 pp.
19   • U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA
20   815-R-99-014.
21
22   Refer to Section 5.1 for additional information on switching from chlorine to chloramines.
23

Increased lead in tap water
Description The use of chloramines can lead to nitrification in the distribution system. This in turn can lower the pH of the water and increase its corrosivity, causing increased levels of metals such as lead, copper, and iron in water in the distribution system. In addition, because chloramines have a lower oxidation potential than chlorine, switching from chlorine to chloramines is suspected to cause lead in pipes to change to a form that is more soluble. This can also increase the lead concentration in the water in the distribution system.

Further Reading
 	
    • AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water
      Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
    • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution
      Systems. AWWARF Report 90983. Project #2648.

Change/disruption of scale
Description The use of chloramines can lead to nitrification in the distribution system. Nitrification can lower the pH of the water, causing disruption to scales formed from corrosion byproducts or protective scales, such as calcium carbonate.
Further Reading • U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999. • AWWA. 1990. Water Quality and Treatment. F.W. Pontius (editor). McGraw-Hill, New York, NY. • AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725. • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648. • Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.
Taste and odor
Description Monochloramine is a preferred chlorine residual with regard to odor quality and customer perceptions. Dichloramine can add a more pungent, sharper chlorine-type odor to the water at lower levels such that some utilities have set a goal to keep the percentage dichloramine of the total combined chlorine residual not to exceed 20% (ref. Lines 11-12 page 7-6). Monochloramine is preferred over free chlorine as it takes a higher level to reach odor detection by customers, and changes in odor following changes in the residual are much less noticeable by customers. However, there have been reports of off-odors associated with nitrification, which could come from biological growth, loss of chloramine residual and related conditions.
Further Reading • Singer, P.C. 1999. Formation and Control of Disinfection By-Products in Drinking Water. AWWA. Denver, CO. 424 pp. • AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp. • Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357. • Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO. • Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.

Increased coliform bacteria

Description

The use of chloramines can lead to nitrification in the distribution system. The nitrite formed through nitrification exerts a high chlorine demand, which will rapidly deplete the disinfectant residual (Cowman and Singer 1994). When the disinfectant residual is low or depleted, microorganisms such as coliforms and heterotrophic bacteria can proliferate.

Further Reading

- White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.
- Kirmeyer, G.J. et al. 1995. Nitrification Occurrence and Control in Chloraminated Water Systems. AWWARF Report 90669. Project #710.
- Connell, G. 1996. The Chlorination/Chloramination Handbook. AWWA. Denver, CO. 174 pp.
- AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.
- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.
- Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Increased heterotrophic bacteria

Description

The use of chloramines can lead to nitrification in the distribution system. The nitrite formed through nitrification exerts a high chlorine demand, which will rapidly deplete the disinfectant residual (Cowman and Singer 1994). When the disinfectant residual is low or depleted, microorganisms such as coliforms and heterotrophic bacteria can proliferate.

Further Reading

- White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.
- Cowman, G.A., and P.C. Singer. 1994. Effect of Bromide Ion on Haloacetic Acid Speciation Resulting from Chlorination and Chloramination of Humic Extracts. Conference proceedings, AWWA Annual Conference, New York, NY.
- Connell, G. 1996. The Chlorination/Chloramination Handbook. AWWA. Denver, CO. 174 pp.
- AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.
- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.
- Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Nitrite/nitrate formation
Description Nitrification can occur when chloramines are used to maintain a residual in the distribution system due to the presence of ammonia, which is used to form chloramines. Nitrifying bacteria convert the excess ammonia into nitrite and nitrate. Nitrification is not a problem when chlorine is used to maintain a residual, because no ammonia is used.
Further Reading   - Kirmeyer, G.J. et al. 1995. Nitrification Occurrence and Control in Chloraminated Water Systems. AWWARF Report 90669. Project #710.   - Connell, G. 1996. The Chlorination/Chloramination Handbook. AWWA. Denver, CO. 174 pp.   - AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.   - Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.   - Connell, G. 1996. The Chlorination/Chloramination Handbook. AWWA. Denver, CO. 174 pp.   - AWWARF. 2004b. Update of Optimizing Chloramine Treatment Project #2760.   - Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.   - Cowman, G.A., and P.C. Singer. 1994. Effect of Bromide Ion on Haloacetic Acid Speciation Resulting from Chlorination and Chloramination of Humic Extracts. Conference proceedings, AWWA Annual Conference, New York, NY.   - Harrington, G.W., D.R. Noguera, C.C. Bone, A.I. Kandou, P.S. Oldenburg, J.M. Regan, and D. Van Hoven. 2003. Ammonia from Chloramine Decay: Effects on Distribution System Nitrification. AWWARF Report 90949. Project #553.   - Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.   - Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.   - White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.
Change in DBP concentration/composition
Description Chloramines react more slowly with organic matter than free chlorine does. Therefore, switching from chlorine to chloramines can significantly reduce DBP formation. However, it will not completely eliminate DBP formation - TTHM and HAA5 will still be formed, though this formation may be undetectable, largely as a result of excess free chlorine or the hydrolysis of monochloramine to from free chlorine.
Further Reading   - U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.   - Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.   - Valentine, R. 2001. Mechanisms and Kinetics of Chloramine Loss and By-Product Formation in the Presence of Reactive Drinking Water Distribution System Constituents. USEPA.

SWITCHING COAGULANT

The following impacts to your distribution system may result from switching your coagulant:

- Change in finished water pH
- Increased lead and copper in tap water
- Change/disruption of scale
- Change in finished water NOM
- Change in chloride:sulfate ratio

The following references can provide further information about how to address most of these impacts. Additional references and brief descriptions are listed by impact in the table below.

- U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
- U.S. EPA. 1999h. Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual. Office of Water. EPA 815-R-99-012.

Refer to Sections 3.3 and 3.7 for additional information on switching coagulants.

Change in finished water pH
Description Different coagulants have different optimum pH ranges. Therefore, when switching coagulants, it may be necessary to adjust the pH to achieve maximum contaminant removal. In addition, some coagulants consume alkalinity, which results in decreased buffering capacity and allows the pH to change more easily.

Further Reading
 	
    • Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
    • Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.

Increased lead and copper in tap water
Description The optimal pH range for coagulants varies by coagulant. Therefore, switching coagulants can require a pH change, and if the pH is significantly reduced, can lead to increased lead and copper corrosion in the distribution system.

Further Reading
 	
    • U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
    • AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
    • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Change/disruption of scale
Description The optimal pH range for coagulants varies by coagulant. Therefore, switching coagulants can require a change in the operating pH, and consequently, in the distribution system. A higher pH can decrease the rate of corrosion, thereby decreasing the formation of scales from corrosion byproducts. A higher pH can also allow the formation of a protective calcium carbonate scale. A lower pH can cause disruption or dislodgement of scales formed from corrosion byproducts or protective scales, such as calcium carbonate.
Further Reading   - Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.   - Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.
Change in finished water NOM
Description To accomplish enhanced coagulation, systems may switch coagulants to improve removal of TOC, which is a surrogate measure of NOM. Therefore, the NOM entering the distribution system is significantly reduced. Some NOM in the finished water can help inhibit corrosion.
Further Reading   - Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.   - Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.
Change in chloride:sulfate ratio
Description Some coagulants, such as aluminum sulfate (alum) and ferric sulfate add sulfate to the water. Other coagulants, such as ferric chloride add chloride to the water. Therefore, switching to or from any of these coagulants can affect the chloride to sulfate ratio. A shift in the sulfate to chloride ratio can cause increased lead and copper corrosion and can alter iron corrosion in the distribution system.
Further Reading   Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.

MODIFYING CHLORINE DOSE WITH WARMER WATER TEMPERATURES

The following impacts to your distribution system may result from reducing chlorine dose during warmer water temperatures in order to reduce DBP formation:

- Increased coliform and heterotrophic bacteria
- Increased loss of chlorine residual in the distribution system

The following references can provide further information about how to address this distribution system impact:

- White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.
- Connell, G. 1996. The Chlorination/Chloramination Handbook. AWWA. Denver, CO. 174 pp.
- Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.
- AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.
- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.
- Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.
- U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.

Increased coliform and heterotrophic bacteria
Description
Chlorine is a more effective disinfectant at higher temperatures. However, because it reacts more quickly at warmer temperatures, the chlorine residual may dissipate more quickly in the distribution system, leaving low or no residual near the end of the distribution system. This can allow increased microbial growth in these areas. In addition, the growth rate of microorganisms is more rapid at higher temperatures, making them more difficult to control. These factors can lead to increased coliform and heterotrophic bacteria if the chlorine dose is lowered during warmer water temperatures.
Increased loss of chlorine residual
Description
Lowering the chlorine dose will mean that there is less residual in the distribution system. Higher temperatures will also cause reactions of the residual with chlorine demand to proceed faster.

1   **ADDING/DISCONTINUING SOFTENING**
2
3   The following impacts to your distribution system may result from adding or discontinuing
4   softening:
5
6   • Change in finished water pH
7   • Increased lead and copper in tap water
8   • Change/disruption of scale
9   • Taste and color problems
10   • Change in finished water NOM
11   • High iron
12   • Change in DBP concentration/composition
13   • Pinhole leaks
14
15   The following reference can provide further information about how to address all of these
16   impacts. Additional references and brief descriptions are listed by impact in the table below.
17
18   • U.S. EPA. 1999h. Enhanced Coagulation and Enhanced Precipitative Softening
19   Guidance Manual. Office of Water. EPA 815-R-99-012.
20
21   Refer to Section 3.8 for additional information on adding or discontinuing softening.
22

Change in finished water pH
Description In enhanced softening, the pH of the water is typically raised to a value above 10. However, most other water treatment processes are operated at much lower pHs. Therefore, when switching to enhanced softening, systems can expect to have a much higher finished water pH. Conversely, if a system switches from enhanced softening to another technology, the operating and finished water pH will be much lower.

Further Reading
 	
    • Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
    • Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.

Increased lead and copper in tap water
Description In enhanced softening, the pH of the water is typically raised to a value above 10. However, most other water treatment processes are operated at much lower pHs. Therefore, when discontinuing softening, systems can expect to have a much lower finished water pH. As the pH decreases, systems can expect an increase in corrosion of distribution system pipes, resulting in increased concentrations of metals such as iron, copper, and lead in the water.

Further Reading

- AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Change/disruption of scale

Description

Installing softening requires an increase in operating pH, while discontinuing softening requires a reduction in pH. A higher pH can decrease the rate of corrosion, thereby decreasing the formation of scales from corrosion byproducts. A higher pH can also allow the formation of a protective calcium carbonate scale. A lower pH can cause disruption or dislodgement of scales formed from corrosion byproducts or protective scales, such as calcium carbonate.

Further Reading

- AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Taste and color problems

Description

Aluminum can be found in source water or introduced through coagulant use or as an impurity in lime. Aluminum is more soluble at high pH. Since enhanced softening is conducted at high pH, it allows more aluminum to pass through the treatment plant. In waters with high magnesium, enhanced softening can form lighter floc, which may not settle as well. This can also allow higher levels of aluminum to enter the distribution system. When aluminum precipitates out in the distribution system it can cause colored water and taste complaints.

Further Reading

- AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.
- Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.
- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.
- Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.

Change in finished water NOM
Description Enhanced softening preferentially removes high molecular weight organic molecules and organic molecules with oxygen-containing functional groups. NOM removal through enhanced softening varies widely depending on the nature and concentration of the NOM, water quality characteristics such as hardness, other plant treatment processes, and type and dose of the softening chemical. Some NOM in the finished water can help inhibit corrosion.
Further Reading   - AWWA. 1990. Water Quality and Treatment. F.W. Pontius (editor). McGraw-Hill, New York, NY.   - AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.   - Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.   - Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.

High iron
Description In enhanced softening, the pH of the water is typically raised to a value above 10. However, most other water treatment processes are operated at much lower pHs. Therefore, when discontinuing softening, systems can expect to have a much lower finished water pH. As the pH decreases, systems can expect an increase in corrosion of distribution system pipes, resulting in increased concentrations of metals such as iron, copper, and lead in the water.
Further Reading   - AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.   - Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Change in DBP concentration/composition
Description Softening removes DBP precursors, reducing the formation of DBPs. Therefore, by installing softening, systems can decrease TTHM and HAA5 levels in the plant and the distribution system. Systems installing softening will also see a shift in the balance of DBPs in the distribution system because TTHM formation is favored over HAA5 formation at the high pH levels used in softening. In addition, prechlorination with softening can reduce the amount of DBP precursor removal (AWWA 1990) and should be avoided if possible.

Further Reading

- AWWA. 1990. Water Quality and Treatment. F.W. Pontius (editor). McGraw-Hill, New York, NY.
- Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Pinhole leaks

Description

Adding softening raises pH and alkalinity of the finished water. Discontinuing softening lowers the pH and alkalinity. Lower pH can be corrosive to copper, but high pH in the absence of inhibitors such as NOM has also been shown to initiate pitting corrosion in copper.

Further Reading

- Edwards, M., J.C. Rushing, S. Kvech, and S. Reiber. 2004. Assessing copper pinhole leaks in residential plumbing. Water Science and Technology. 49(2): 83-90.
- Edwards, M., J.F. Ferguson, S. Reiber. 1994. The Pitting Corrosion of Copper. Journal of American Water Works Association. 86(7): 74-91.
- AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.

1

ADDING OZONE

The following impacts to your distribution system may result from adding ozone:

- Increased lead and copper in tap water
- Taste and odor
- Change in finished water NOM
- Colored water
- High iron
- Change in DBP concentration/composition

The following references can provide further information about how to address most of these impacts. Additional references and brief descriptions are listed by impact in the table below.

- U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.

Refer to Section 5.2 for additional information on adding ozone.

Increased lead and copper in tap water
Description When ozone reacts in water it produces dissolved oxygen. Dissolved oxygen can cause increased growth of aerobic bacteria, which can lead to microbial-induced corrosion in the distribution system. Dissolved oxygen is also corrosive, and if not removed, it can directly cause lead and copper corrosion in the distribution system. Ozonation also breaks down organics into smaller molecules that are more readily used as a food source by microorganisms. If not removed, this can lead to increased microbial growth and microbial-induced corrosion in the distribution system.

Further Reading
 	
    • White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.
    • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Taste and odor
Description Ozonation reacts with organics to break them down into smaller molecules, such as aldehydes and ketones. Aldehydes can impart tastes and odors to water. In addition, ozone itself can impart an "ozonous" or "oxidant" taste to the water even in the absence of a residual (AWWARF and Lyonnaise des Eaux 1995).
Further Reading   - AWWARF and Lyonnaise des Eaux, 1995. Advances in Taste and Odor Treatment and Control.   - Singer, P.C. 1999. Formation and Control of Disinfection By-Products in Drinking Water. AWWA. Denver, CO. 424 pp.   - AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.   - Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.   - Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.   - Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.   - Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.
Change in finished water NOM
Description Ozone reacts with NOM in water to destroys many DBP precursors. However, ozone breaks the NOM down into smaller organic molecules that are readily used as a food source by microorganisms, referred to as AOC. If ozone is followed by biological filtration, the AOC concentration can also be significantly reduced.
Further Reading   - Singer, P.C. 1999. Formation and Control of Disinfection By-Products in Drinking Water. AWWA. Denver, CO. 424 pp.   - Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.   - Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.
Colored water
Description Ozonation produces dissolved oxygen in water, which is corrosive. In addition, dissolved oxygen can cause increased microbial activity in the distribution system and microbial-induced corrosion. If iron pipe is present in the distribution system, increased corrosion can lead to colored water problems.

Further Reading

- White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.
- Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.
- AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.
- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.

High iron

Description

Ozonation produces dissolved oxygen in water, which is corrosive. In addition, dissolved oxygen can cause increased microbial activity in the distribution system and microbial-induced corrosion. If iron pipe is present in the distribution system, increased corrosion can lead to higher iron levels in the water.

Further Reading

- U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
- White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Change in DBP concentration/composition

Description

Ozone does not form chlorinated DBPs. Therefore, switching from chlorine or chlorine dioxide as a primary disinfectant to ozone will result in significantly lower levels of TTHM and HAA5. However, ozone reacts with bromide to form bromate, which is a regulated DBP.

Further Reading

- Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

1   **ADDING CHLORINE DIOXIDE**
2
3   The following impacts to your distribution system may result from adding chlorine dioxide:
4
5   • Increased lead and copper in tap water
6   • Taste and odor
7   • Change in finished water NOM
8   • Colored water
9   • High iron
10   • Change in DBP concentration/composition
11
12   References, along with brief descriptions, that are specific to individual issues are listed by
13   impact in the table below. Refer to Sections 5.4 and 5.5 for additional information on adding
14   chlorine dioxide.
15

Increased lead and copper in tap water
Description Changing to chlorine dioxide from another oxidant can change the oxidation/reduction potential of the tap water. Changes in oxidation/reduction potential can alter the nature of passivating layers and could result in the release of lead and other metals into the distribution system. It is also possible that AOC formed by chlorine dioxide could encourage microbial-induced corrosion.
Further Reading • AWWA. 2004c. Draft. Managing Lead and Copper Rule Corrosion Control Practices to Avoid Unintended Consequences. • AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725. • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.
Taste and odor
Description Chlorine dioxide has a strong chlorinous odor. Even when chlorine dioxide is used only as a primary disinfectant, customers may still detect a strong chlorinous odor at the tap as chlorite can combine with free chlorine in the distribution system to form chlorine dioxide. If a customer has recently installed new carpeting, airborne organic compounds from the carpeting can react with the chlorine dioxide emanating from the customer's tap to form offensive odors. These odors have been described as "cat-urine-like" and "kerosene-like" (Hoehn et al. 1990).

Further Reading

- AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.
- Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.
- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.
- Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.

Change in finished water NOM

Description

Chlorine dioxide reacts with organic matter in water. These reactions can form smaller organic molecules or AOC. Although AOC production is not as much of an issue with chlorine dioxide as it is with ozone, it is still possible AOC could increase and in turn increase microbial growth.

Further Reading

- U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- Andrews, R.C. et al. 2005. Impact of Chlorine Dioxide on Transmission, Treatment, and Distribution System Performance. AWWARF Report 91082. Project #2843.
- AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.
- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.

Colored water

Description

Chlorine dioxide can react with organic chemicals to form AOC. AOC can act as a food source for microbes, which can in turn increase the corrosion rate causing corrosion products to be released into the distribution system. The change in oxidation/reduction potential can also destabilize some already formed layers of corrosion products, leading to colored water.

Further Reading

- U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- Andrews, R.C. et al. 2005. Impact of Chlorine Dioxide on Transmission, Treatment, and Distribution System Performance. AWWARF Report 91082. Project #2843.
- Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.
- AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.
- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.

High iron
Description Chlorine dioxide can react with organic matter to form AOC which can cause microbial-induced corrosion. Changes in water oxidation/reduction potential resulting from chlorine dioxide use may also allow dissolution of existing scales.

Further Reading
 	
    • U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
    • Andrews, R.C. et al. 2005. Impact of Chlorine Dioxide on Transmission, Treatment, and Distribution System Performance. AWWARF Report 91082. Project #2843.
    • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Change in DBP concentration/composition
Description Chlorine dioxide does not form significant amounts of TTHM or HAA5. Therefore, switching from chlorine or chloramines to chlorine dioxide will result in lower levels of these DBPs. However, chlorine dioxide generators produce some chlorine as a byproduct so some TTHM and HAA5 will be formed. In addition, chlorine dioxide can oxidize bromide ions to bromine, which can then react with organic matter in the water to produce brominated DBPs. Chlorine dioxide also reacts with NOM to produce chlorite, which is a regulated DBP.

Further Reading
 	
    • U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
    • White, G.C. 1999. Handbook of Chlorination and Alternative Disinfectants. Fourth ed. Van Nostrand Reinhold Co., New York, NY.
    • Gates, D. 1997. The Chlorine Dioxide Handbook. AWWA. Denver, CO.
    • Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.
    • Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.

1

1   **ENHANCED COAGULATION**
2
3   The following impacts to your distribution system may result from using enhanced coagulation:
4
5   • Reduction in finished water pH
6   • Increased lead and copper in tap water
7   • Change/disruption of scale
8   • Change in finished water NOM
9   • Change in DBP concentration/composition
10   • Change in chloride:sulfate ratio
11
12   The following references can provide further information about how to address most of these
13   impacts. Additional references and brief descriptions are listed by impact in the table below.
14
15   • U.S. EPA. 1999h. Enhanced Coagulation and Enhanced Precipitative Softening
16   Guidance Manual. Office of Water. EPA 815-R-99-012.
17   • U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous
18   Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
19
20   Refer to Section 3.7 for additional information on using enhanced coagulation.
21

Change in finished water pH
Description Enhanced coagulation tends to reduce the pH of the water. This can be accomplished by adding chemicals specifically to reduce the pH to as low as 5.5 or as a consequence of using heavy alum or ferric coagulant doses.

Further Reading
 	
    • Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
    • Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.

Increased lead and copper in tap water
Description Enhanced coagulation tends to reduce the pH of the water. This can be accomplished by adding chemicals specifically to reduce the pH to as low as 5.5 or as a consequence of using heavy alum or ferric coagulant doses. In addition, switching coagulants for enhanced coagulation can lead to reduced pH. A reduction in pH can cause increased lead and copper corrosion.

22

Further Reading

- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Change/disruption of scale

Description

Enhanced coagulation tends to reduce the pH of the water. This can be accomplished by adding chemicals specifically to reduce the pH to as low as 5.5 or as a consequence of using heavy alum or ferric coagulant doses. A lower pH can cause disruption or dislodgement of scales formed from corrosion byproducts or protective scales, such as calcium carbonate.

Further Reading

- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Change in finished water NOM

Description

Enhanced coagulation increases the removal of TOC, which is a surrogate measure of NOM. Therefore, the NOM entering the distribution system is significantly reduced. Some NOM in finished water can help inhibit corrosion.

Further Reading

- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.

Change in DBP concentration/composition

Description

Enhanced coagulation improves the removal of DBP precursors in a conventional water treatment plant, reducing the formation of DBPs. Therefore, by practicing enhanced coagulation, systems can decrease TTHM and HAA5 levels in the plant and the distribution system.

Further Reading

- Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Change in chloride:sulfate ratio
Description One option for systems initiating enhanced coagulation is to switch coagulants to increase TOC removal. Some coagulants, such as aluminum sulfate (alum) and ferric sulfate add sulfate to the water. Other coagulants, such as ferric chloride add chloride to the water. Therefore, switching to or from any of these coagulants can affect the chloride to sulfate ratio and, as a result, may cause increased lead and copper corrosion.
Further Reading • Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.

1

1   **INSTALLING NANOFILTRATION**
2
3   The following impacts to your distribution system may result from installing nanofiltration:
4
5   • Change in finished water pH
6   • Increased lead and copper in tap water
7   • Change/disruption of scale
8   • Change in finished water NOM
9   • Colored water
10   • High iron
11   • Change in DBP concentration/composition
12   • Pinhole leaks
13
14   The following reference can provide further information about how to address most of these
15   impacts. Additional references and brief descriptions are listed by impact in the table below.
16
17   • AWWA. 1999b. Reverse Osmosis and Nanofiltration. AWWA Manual M46. 178 pp.
18
19   Refer to Section 4.3 for additional information on installing nanofiltration.
20

Change in finished water pH
Description Nanofiltration can remove virtually all particulate matter as well as larger dissolved compounds. However, it cannot remove dissolved gasses. Therefore, carbon dioxide in the feed water is not removed, while alkalinity, hardness, and other dissolved compounds are removed. Therefore, the carbonate system must re-equilibrate, resulting in the production of the hydrogen ion and loss of alkalinity. This in turn results in a lowering of the pH of the water.
Further Reading • Schippers, J.C. 2004. Integrated Membrane Systems. AWWARF Report 90899. Project #264. • Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357. • Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.
Increased lead and copper in tap water
Description Nanofiltration can also result in a lowering of the pH of the water. The lower pH water will be more corrosive to lead and copper piping in the distribution system. As a result, both increased lead and copper levels can occur.

Further Reading

- AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Change/disruption of scale

Description

Nanofiltration can also result in a lowering of the pH of the water. A lower pH can cause disruption or dislodgement of scales formed from corrosion byproducts or protective scales, such as calcium carbonate.

Further Reading

- AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Change in finished water NOM

Description

Nanofiltration is a physical process that removes molecules from water. Nanofiltration can remove both particulate matter and dissolved compounds, including NOM. Thus, the NOM concentration entering the distribution system is significantly reduced. Some NOM in finished water can help inhibit corrosion.

Further Reading

- AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.
- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.

Colored water

Description

Nanofiltration can also result in a lowering of the pH of the water. The lower pH water will be more corrosive to iron pipe in the distribution system. The corrosion will result in increased iron in the water, which can lead to colored water problems.

Further Reading

- AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
- Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.
- AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.
- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.

High iron

Description

Nanofiltration can also result in a lowering of the pH of the water. The lower pH water will be more corrosive to iron pipe in the distribution system. Corrosion of iron pipe will result in increased iron in the water.

Further Reading

- AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. Optimizing Corrosion Control in Distribution Systems. AWWARF Report 90983. Project #2648.

Change in DBP concentration/composition

Description

Nanofiltration physically removes DBP precursors, reducing the formation of DBPs. Therefore, by installing nanofiltration, systems can decrease TTHM and HAA5 levels in the plant and the distribution system.

Further Reading

- Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Pinhole leaks

Description

Nanofiltration can remove most larger particles and many smaller ones. This includes NOM, which has been shown to inhibit pitting corrosion in copper piping.

Further Reading

- Edwards, M., J.C. Rushing, S. Kvech, and S. Reiber. 2004. Assessing copper pinhole leaks in residential plumbing. Water Science and Technology. 49(2): 83-90.
- Edwards, M., J.F. Ferguson, S. Reiber. 1994. The Pitting Corrosion of Copper. Journal of American Water Works Association. 86(7): 74-91.
- AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.

INSTALLING GRANULAR ACTIVATED CARBON

The following impacts to your distribution system may result from installing granulated activated carbon (GAC):

- Increased coliform and heterotrophic bacteria

The following references can provide further information about how to address this impact. A brief description of the distribution system impact is provided in the table below.

- AWWA. 1990. Water Quality and Treatment. F.W. Pontius (editor). McGraw-Hill, New York, NY.
- American Chemical Society. 1983. Treatment of Water by Granular Activated Carbon. M.J. McGuire and I.H. Suffet (eds). ACS, Washington, D.C.
- Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second Edition. AWWA. Denver, CO. 278 pp.
- AWWA. 2003a. Principles and Practices of Water Supply Operations: Water Transmission and Distribution, Third Edition. 553 pp.
- Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water Quality. AWWARF Report 90798. Project #357.
- Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver, CO.
- Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.
- Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Refer to Section 4.1 for additional information on installing GAC.

Increased coliform and heterotrophic bacteria
Description
Heterotrophic bacteria can colonize GAC filters and can be shed in the filter effluent. The number of bacteria in the effluent of GAC systems is frequently higher than influent levels. This problem is compounded when GAC filters are operated in biologically active mode, where biological growth on the GAC filters is promoted.

1   **INSTALLING OZONE WITHOUT SUBSEQUENT BIOLOGICAL FILTRATION**
2
3   The following impact to your distribution system may result from installing ozone without
4   subsequent biological filtration:
5
6   • Increased coliform and heterotrophic bacteria
7
8   The following references can provide information about how to address this impact. A brief
9   description of the distribution system impact is provided in the table below.
10
11   • Singer, P.C. 1999. Formation and Control of Disinfection By-Products in Drinking
12   Water. AWWA. Denver, CO. 424 pp.
13   • U.S. EPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA
14   815-R-99-014.
15   • U.S. EPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous
16   Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
17   • Von Huben, H. 1999. Water Distribution Operator Training Handbook, Second
18   Edition. AWWA. Denver, CO. 278 pp.
19   • AWWA. 2003a. Principles and Practices of Water Supply Operations: Water
20   Transmission and Distribution, Third Edition. 553 pp.
21   • Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water
22   Quality. AWWARF Report 90798. Project #357.
23   • Lauer, W.C., ed. 2005. Water Quality in the Distribution System. AWWA. Denver,
24   CO.
25   • Mays, L.W. 1999. Water Distribution Systems Handbook. AWWA. Denver, CO.
26   • Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA.
27   Denver, CO. 85 pp.
28
29   Refer to Section 5.2 for additional information on installing ozone without subsequent biological
30   filtration.
31

Increased coliform and heterotrophic bacteria
Description
Ozone reacts with NOM in water to destroys many DBP precursors. However, ozone breaks the NOM down into smaller organic molecules that are readily used as a food source by microorganisms, referred to as assimilable organic carbon (AOC). If ozone is followed by biological filtration, the AOC concentration can be significantly reduced. However, if ozone is not followed by biological filtration, the AOC will pass into the distribution system where it can be readily used by microorganisms. This will result in increased heterotrophic bacterial growth and possibly higher coliform numbers and may cause nitrification in chloraminated systems.

32

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25   This page intentionally left blank.

1   **Appendix D**
2   **Tools for Evaluating Impacts of Treatment Changes on**
3   **Lead and Copper Rule Compliance**

1
2
3   This page intentionally left blank.
4

1 **Appendix D Tools for Evaluating Impacts of Treatment Changes on Lead and**
2 **Copper Rule Compliance**
3
4   Many things can cause corrosion of piping and appurtenances in the distribution system.
5 Changes in pH, alkalinity, microbiological growth, oxidation reduction potential of the water,
6 and electric currents passing through the piping can increase corrosion rates. While corrosion is
7 always a concern, if it occurs in distribution system elements containing lead or copper, it can
8 result in an exceedence of Lead and Copper Rule (LCR) action levels.
9
10   Because corrosion can lead to increased levels of lead and copper at the tap, prevention
11 and quick responses are important. Corrosion assessment tools can be valuable for preventing
12 corrosion and responding to it when it occurs. This appendix gives brief descriptions of tools
13 that can be used to examine impacts of water quality change on corrosion, and to identify and
14 locate existing corrosion problems. It also provides references where more in-depth information
15 can be found.
16
17   Corrosion assessment tools can be used in several different ways. In cases where
18 corrosion has already become a problem, they can be used to determine where and why it is
19 occurring and to test alternative corrosion control strategies. If used prior to a treatment change,
20 they can be used to assess the potential impact of the treatment change on corrosion. They can
21 also be used to select appropriate materials that will perform the best for a given water quality.
22
23 **D.1   Desktop Studies**
24
25 *Description of Method*
26
27   A desktop evaluation should aim to document the extent, magnitude and possible causes
28 of a potential problem by developing and assessing options, identifying constraints on the system
29 and recommending actions for systems to implement. Desktop studies can include:
30
31 • literature reviews
32
33
34 • mathematical modeling
35
36 • review of past findings
37
38 • review of standards and guidance documents
39
40 • expert opinion, and
41

1   • consultation with other systems with similar water quality and distribution systems
2   Desktop studies typically examine the literature to find information. Case studies of systems
3   with similar problems can be helpful. For example, AWWA's Water Industry Technical Action
4   Fund conducted a survey of lead and copper leaching in 400 US water systems. The survey
5   gives 90th percentile lead and copper values for each of the 400 systems along with other water
6   quality data such as pH, alkalinity, calcium, and the any corrosion inhibitor used. Systems could
7   use such data to discern general trends in corrosion with changes in water quality programs, or
8   they could look specifically for systems with similar water quality to their own and find what
9   was worked for those systems.
10
11 Literature reviews of laboratory studies may help reveal mechanisms and possible corrosion
12 prevention strategies. Contacting consultants or researchers familiar with the problem or
13 systems that have encountered similar problems can also aid in finding a solution. Computer
14 models can be helpful for predicting potential corrosion problems. Chemical solubility models
15 can predict the thermodynamic stability of a given metal in a specific water quality. These
16 solubility models may be especially useful for lead corrosion. Blending analysis programs can
17 predict the water quality of multiple sources blended in a distribution system and help determine
18 if and where corrosive conditions might result. In cases where models may not be sufficient, jar
19 testing can help show how treatment changes can change finished water quality.
20
21 *Uses and Limitations*
22
23   Desktop studies can be useful prior to changes to determine potential corrosion problems.
24 They can also be used to find solutions to existing corrosion problems. They are a relatively
25 inexpensive ways to narrow down the number of potential solutions to a corrosion problem.
26 They can draw off other's expertise and minimize time spent on testing ineffectual techniques.
27
28   Desktop studies, however, are limited in that they do not apply exactly to a specific
29 system's water quality and configuration. For this reason, they can rarely be used alone but are
30 often used in combination with other methods.
31
32 *References*
33
34   Hecht, P.M., and E.A. Turner. 2004. Washington Aqueduct Desktop & Flow-Through
35   Study. Presented at Getting the Lead Out: Analysis & Treatment of Elevated Lead
36   Levels in DC's Drinking Water at the 2004 AWWA WQTC.
37
38   AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water
39   Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
40
41   AWWA 1993. Initial Monitoring Experiences of Large Water Utilities Under USEPA's
42   Lead and Copper Rule. Sponsored by the WITAF. Denver Colorado.

1
2
3   **D.2   Expanded Baseline Monitoring**
4
5   *Description of Method*
6
7   The LCR requires systems to measure water quality parameters in the distribution
8   system. These parameters include: pH, alkalinity, calcium, conductivity, temperature, and the
9   concentration of any corrosion inhibitors, as determined by the primacy agency and the corrosion
10   control permit. Samples give useful information on the state of corrosion within the distribution
11   system. By expanding this monitoring throughout the system and performing it at more frequent
12   intervals, better information on potential trouble spots within the system can be determined. For
13   example, bacteriological data from TCR compliance monitoring can help systems identify areas
14   likely to suffer from biologically enhanced corrosion. Water quality parameteter monitoring
15   conducted at TCR sample sites can help systems identify LCR compliance issues.
16
17   *Usefulness and Limitations*
18
19   Monitoring can provide systems with a good sense of areas of the system that have
20   potentially corrosive waters or may be experiencing biologically induced corrosion. It can also
21   show how effective a corrosion inhibitor is performing. It cannot predict corrosion rates or
22   predict successful corrosion control strategies. Burlingame and Sandvig (2004) provides an
23   example of how one system used evaluate lead and copper data to determine if changes in
24   operations, treatment, or source were impacting lead and copper corrosion rates.
25
26   *References*
27
28   U.S. EPA 2002c. Lead and Copper Monitoring and Reporting Guidance for Public Water
29   Systems. Office of Water. EPA 816-R-02-009.
30
31   Kirmeyer, G.J. 2000b. Guidance Manual for Maintaining Distribution System Water
32   Quality. AWWARF Report 90798. Project #357.
33
34   Burlingame, G.A. and A. Sandvig. 2004. How to Mine Your Lead and Copper Data.
35   Opflow. 30(6):16-19.
36
37
38   **D.3   Coupon Techniques**
39
40   *Description of Method*
41

1   Coupon techniques are a commonly used technique to evaluate the corrosion of a given
2   distribution system metal for a given water quality. Coupon techniques place a small sample or
3   coupon of metal in flowing water that is the same as, or closely replicates, the water that will be
4   used in the distribution system. Flow conditions also replicate those that will be experienced in
5   the system as closely as possible.
6
7   Traditional coupon techniques have involved flat metal coupons mounted in a flow
8   stream. These include methods ASTM D2688-83 method B, ASTM G1-81, ASTM G46-76, and
9   the Water Research Center Coupon Rig. Other techniques have been developed that use actual
10 pipe lengths. These include ASTM D2688-83 method C, Modified ISWS Coupon sleeve tester,
11 Corps of Engineers Research Lab tester, Ringsaulen protocol, and the TZW Karlsruhe protocol.
12
13   Coupon preparation is important in order to obtain consistent corrosion rates, since the
14 corrosion rate is highly dependent on the properties of the corroding surface. There are several
15 different coupon preparation techniques, which include a variety of steps. Steps can include:
16
17   • machining,
18   • deburring,
19   • degreasing,
20   • paint removal,
21   • acid wash,
22   • application of exterior epoxy,
23   • drying, and
24   • weighing.
25
26 Once the coupons are prepared, they are placed in the flow stream. Coupons are sacrificed
27 periodically and the total weight loss is measured. It is necessary to ensure that enough coupons
28 are used to obtain a statistically valid corrosion rate. Because corrosion rates vary over time as
29 passivating layers form, coupon experiments must be done over a relatively long time span. Test
30 periods can range from 1 month to 2 years. In addition, rates must also be reported over a
31 standardized time frame to be comparable to other measured corrosion rates.
32
33   If pitting corrosion occurs, weight measurements can be combined with other visual
34 inspection techniques to better determine potential useful life of the material. These visual
35 techniques are described in ASTM G46-76.
36
37 *Usefulness and Limitations*
38
39   Coupon techniques are best suited for determining likely corrosion rates that can be
40 expected for given water quality conditions and a given metal. They are well suited for trending
41 corrosion rates because actual water quality conditions and the actual metal are used. They can
42 also be very useful in selecting new materials to be used for distribution system expansion or

1 rehabilitation. When combined with visual inspection techniques, coupon methods can give a
2 good prediction of the expected service length of a given material in given water quality
3 conditions.
4
5   Because coupon techniques take a long time, they are not usually appropriate for
6 determining an early warning to a new problem. Coupon methods also measure weight loss and
7 this has not always correlated well with measurements of metal in water samples (Schock 1996).
8 In addition, coupon rates only measure total weight loss, so they may not be adequate for
9 predicting material life of materials that undergo pitting corrosion. For these materials, coupon
10 methods can be combined with inspection and analysis techniques to obtain estimates of material
11 life. The number of coupons, the time involved, and the procedures needed to obtain some
12 precision also make coupon testing a fairly labor intensive method.
13
14 *References*
15
16   ASTM D2688-83 Method B. 1983a. Standard Test Methods for the Corrosivity of Water
17   in the Absence of Heat Transfer (Weight Loss Protocol). American Society for Testing
18   and Materials. Philadelphia, PA.
19
20   ASTM D2688-83 Method C. 1983b. Standard Test Methods for the Corrosivity of Water
21   in the Absence of Heat Transfer (Machined Nipple Test). American Society for Testing
22   and Materials. Philadelphia, PA.
23
24   AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water
25   Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
26
27   ASTM G46-76. 1976. *Recommended Practice for the Examination and Evaluation of*
28   *Pitting Type Corrosion*. American Society for Testing and Materials. Philadelphia, PA.
29
30   ASTM G1-81. 1981. *Recommended Practice for Preparing, Cleaning and Evaluating*
31   *Corrosion Test Specimens*. American Society for Testing and Materials. Philadelphia,
32   PA.
33
34   Schock, Michael. 1996. Corrosion Inhibitor Applications in Drinking Water Treatment:
35   Conforming to the Lead and Copper Rule. Presented at NACE Corrosion 1996
36   Conference.
37
38 **D.4   Pipe Loops**
39
40 *Description of Method*
41

1   Pipe loops use actual pipes to test corrosion rates of water of a given water quality. Pipe
2   loops are most often made up of small diameter piping and are intended to simulate corrosion in
3   the consumer's plumbing.
4
5   Water is circulated through the pipe loop for an extended period of time. There are two
6   types of pipe loops, flow through and recirculating. In flow through pipe loops, water flows
7   through the pipe a single time as in a real system and is discharged to waste. Recirculating pipe
8   loops recirculate the same water through the pipes continuously. In both types of pipe loops
9   water can be stagnant in the pipes for periods of time to represent water use patterns. The water
10 is collected and analyzed for corrosion products. Pipes must be conditioned for a period of time
11 to achieve a stable rate of corrosion.
12
13   Corrosion can be measured in pipe loops using several different methods. These methods
14 include:
15
16   •   potentiodynamic scans,
17   •   electrochemical impedance spectroscopy,
18   •   metals release, and
19   •   oxygen uptake.
20
21   The first two methods are electrochemical techniques. They operate on the principal that
22 corrosion reactions are electrochemical reactions which involve the transfer of electrons and
23 therefore generation of current. Although the corrosion current is very localized and transient,
24 the electrochemical techniques use electrical measurements and corrosion theory to obtain
25 corrosion rates.
26
27   Potentiodynamic scans are a fundamental electrochemical technique, where the surface
28 potential of the pipe specimen is forced continuously from a high potential to a low potential.
29 The potential versus current relationship is recorded. Then using electrokinetic models, the data
30 are used to calculate the corrosion potential of the metal.
31
32   Electrochemical impedance spectroscopy is a relatively new technique that is well suited
33 for drinking water applications. It works similar to other techniques in that an impressed current
34 is applied to the surface and the resulting potential is measured. It differs from techniques in that
35 the current is an alternating current (AC) instead of a direct current (DC). The results are
36 analyzed to create a model of the corrosion surface. This can give a picture of all the
37 components of a corroding surface such as the polarization resistance of the surface and the
38 presence of a passivating layer.
39
40   Metals release measures the concentration of metal released to the water after some
41 stagnation or recirculation period. Both particulate and dissolved forms of the metal can be
42 measured.

Oxygen uptake measures the rate of oxygen consumption from the circulating water. This is assumed to be an indication of the corrosion rate. For it to be effective the corrosion rate must be large enough to cause a significant decrease in dissolved oxygen levels.

Uses and Limitations

Pipe loops are best suited to examine how distribution or plumbing materials will respond to treatment changes or other changes in water quality or to evaluate potential corrosion control strategies. One advantage is that they closely simulate actual distribution systems and the conditions under which corrosion occurs. Their disadvantage is that they can take a relatively long time to conduct and are relatively expensive.

Potentiodynamic scans are best suited for determining corrosion rates, although they are less effective at evaluating pitting corrosion. As with most electrochemical techniques they experience some imprecision from the high internal resistance of the material compared to the low conductivity of water. They also may alter the surface in unknown ways through application of a current and require very careful sample preparation to achieve reproducible results.

Electrochemical impedance spectroscopy is advantageous because it performs well for the low corrosion rates found in water systems. It can also reveal more in-depth information about the nature of the corrosion such as the existence of passivating layers and the other physical components of the corrosion system. Its disadvantage is that it is relatively new and interpretation of results is complex and requires considerable expertise in the area.

Measuring metals release gives a good indication of dissolved metals concentrations that will be seen in the consumer's taps. Measuring metals release alone, however, can lead to an inaccurate total corrosion rate as some metal can be retained on the surface in corrosion scales. Oxygen uptake measurements may miss some corrosion that occurs by mechanisms other than oxidation and is limited to relatively rapidly corroding metals.

References

AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.

Cottis, R.A., S. Turgoose, and R. Newman. 1999. Corrosion Testing Made Easy: Electrochemical Impedance and Noise. National Association of Corrosion Engineers. Houston, TX.

Kirmeyer, G.J., A.M. Sandvig, G.L. Pierson, and C.H. Neff. 1994. Development of a Pipe Loop Protocol for Lead Control. AWWARF Report 90650 Project #604.

1
2 **D.5   Partial System Testing**
3
4 *Description of Method*
5
6   In partial system testing, a corrosion control method is tested on a small part of the
7 distribution system which has been hydraulically isolated from the rest of the system. An
8 outreach program should be in place to the customers in that section of the distribution system
9 informing them of the test and any changes which they might see.
10
11 *Uses and Limitations*
12
13   A partial system test can be very useful in examining system specific issues which might
14 not be obvious from pipe loop tests or other laboratory techniques. For example, partial system
15 tests can help determine whether a given water quality change might lead to red water incidents
16 within the system.
17
18   A partial system test, however, does not guarantee that problems will not occur in the rest
19 of the system as there can still be differences in piping material, temperatures, soil conditions,
20 pipe age and other variables. A partial system test will also require isolating that part of the
21 system and communicating closely with customers in that portion of the system. It may also
22 require setting up temporary chemical feed facilities, which can be expensive.
23 *References*
24
25   Kirmeyer, G.J. et al. 2000a. Distribution System Water Quality Changes Following
26   Implementation of Corrosion Control Strategies. AWWARF Report 90764. Project
27   #157.
28
29 **D.6   Water Line Profiling**
30
31 *Description of Method*
32
33   Elevated lead and copper levels in tap water could originate from a number of locations
34 in the home plumbing system, such as meters, welded joints, service lines, and plumbing
35 fixtures. Water line profiling is a method that can be used to determine from where elevated lead
36 or copper levels are originating. The procedure for performing the profiling is as follows:
37
38   •   Collect data on the diameter and length of the various portions of the plumbing
39   system from the water main to the tap that will be sampled. Determine the volume of
40   water in each section.
41   •   Let the water stagnate for at least 6 hours prior to beginning the test. This can be
42   done while the customer is away from home.

1   • Draw consecutive samples from the tap in 1-liter sample bottles. Samples should be
2   collected at a flow rate of about 2 liters/min.
3   • Measure each sample for lead and copper. It is helpful to measure both dissolved and
4   particulate forms of the metals.
5   • Consider analyzing samples for pH, temperature, and chlorine residual. Other
6   variables such as iron, aluminum, zinc, copper, chlorine residual, nitrite, nitrate, free
7   ammonia and corrosion inhibitors can also be measured.
8
9   Examining the metal concentration across the samples will show where the peak
10   corrosion is occurring in the plumbing system relative to the tap. For example, if the first sample
11   is the highest then the corrosion is likely occurring in the customer's plumbing, a slightly later
12   peak may indicate corrosion of the service line, while an even later peak would point to problems
13   in the water mains.
14
15   *Uses and limitations*
16
17   Profiling is advantageous in that it can give a quick assessment of the source of elevated
18   metals concentration in a customer's tap water. It requires close coordination with the customer,
19   including filtration of the samples in their home if they are to be analyzed for dissolved
20   constituents. In addition, the method only gives a snapshot picture of a single system at a single
21   point in time which may not correspond to corrosion in other areas of the system. This can be
22   alleviated to some degree by sampling in several homes throughout the distribution system.
23   *References*
24
25   Giani, R., M. Edwards, C. Chung, and J. Wujek. 2004. Lead Profiling Methodologies
26   and Results. Presented at Getting the Lead Out: Analysis & Treatment of Elevated Lead
27   Levels in DC's Drinking Water at the 2004 AWWA WQTC.
28
29   **D.7   Laboratory Analysis of Corrosion Products**
30
31   *Description of Method*
32
33   Once corrosion has occurred, the corrosion products can be analyzed using several
34   advanced techniques which can reveal detailed information about the composition and form of
35   the corrosion products. This information may help determine the likely mechanisms of corrosion
36   and the elements involved. These techniques include:
37
38   • X-ray emission spectroscopy,
39
40   • X-ray diffraction, and
41
42   • Auger electron microscopy.

1
2 X-ray emission spectroscopy can give a semi-quantitative analysis of the elemental composition
3 of corrosion products. X-ray diffraction provides a quantitative analysis of the composition of
4 crystalline compounds. It can identify the mineral composition of corrosion scale. Auger
5 electron microscopy can give a depth profile of corrosion scales.
6
7 *Uses and Limitations*
8
9   Surface analyses using the techniques described above can be very useful for determining
10 the composition of corrosion scale and corrosion products, and are therefore useful for systems
11 where corrosion has already occurred. This information can help determine the corrosion
12 mechanism, and therefore the cause of the corrosion, such as oxidation of the pipe, biologically
13 induced corrosion, or reaction with other contaminants. These techniques can also give
14 information on any passivating or barrier layers that can protect pipes from further corrosion.
15 These techniques cannot be used to give quantitative assessments of corrosion rates and metals
16 release. Other methods must be used to obtain that information.
17
18 *References*
19
20   ASTM D934-80. 2003. *Standard Practices for Identification of Crystalline Compounds*
21   *in Water Formed Deposits by X-Ray Diffraction.* American Society for Testing and
22   Materials. Philadelphia, PA.
23
24 **D.8   Electrochemical Methods**
25
26 *Description of Method*
27
28   The electrochemical methods of potentiodynamic scans and electrochemical impedance
29 spectroscopy were described in the section on pipe loops. Several other electrochemical
30 techniques that may be more useful for online monitoring of corrosion include:
31
32   • electrical resistance,
33   • linear polarization, and
34   • electrochemical noise.
35
36   Electrical resistance is a method where the electrical resistance change is measured in a
37 corroding wire. The resistance of the wire changes as it corrodes, and the change in resistance is
38 then correlated to the corrosion rate.
39
40   Linear polarization is a technique that is frequently used for online, continuous
41 measurements. It relies on the fact that near the freely corroding surface potential, the slope of
42 the current versus potential curve is linear. The linear polarization, then, involves a short

1   duration polarization offset within the linear range. The polarization resistance is then converted
2   to a corrosion rate by application of a constant. The constant is highly dependent on water
3   quality and must be evaluated for specific conditions. Generally because of the uncertainty
4   surrounding the constant, this technique is best for determining relative corrosion rates rather
5   than actual corrosion rates.
6
7   Electrochemical noise monitors low frequency changes in the freely corroding surface
8   potential. This is a relatively new technology which is just beginning to find applications in
9   water distribution systems. It is mostly useful for online monitoring.
10
11   *Uses and Limitations*
12
13   These electrochemical techniques are generally imprecise and do not reproduce easily
14   across different conditions. For this reason they are best suited for determining relative
15   corrosion rates within a single system. This makes them best suited for online monitoring to
16   determine real time corrosion rates.
17
18   Electrical resistance is a simple and relatively inexpensive method of online corrosion
19   monitoring. It is relatively imprecise, though, and cannot provide absolute corrosion rates thus
20   the data are not easily applied to situations other than in which it was taken.
21
22   Linear polarization is most useful for online corrosion monitoring and is relatively simple
23   and inexpensive. It is highly site specific, and therefore the data collected cannot be applied to
24   situations other than that in which it was recorded.
25
26   The main advantage of electrochemical noise is that it does not perturb the corroding
27   surface and therefore more closely measures actual corrosion rates. It is also good for online
28   corrosion monitoring. Its disadvantage is that it is relatively expensive and its use is still not
29   standardized in the water industry.
30
31   *References*
32
33   AWWARF and DVGW-Technologiezentrum Wasser. 1996. Internal Corrosion of Water
34   Distribution Systems. 2nd edition. AWWARF Report 90508. Project #725.
35
36   Cottis, R.A., S. Turgoose, and R. Newman. 1999. Corrosion Testing Made Easy:
37   Electrochemical Impedance and Noise. National Association of Corrosion Engineers.
38   Houston, TX.

1   This page intentionally left blank.
2

1   **Appendix E**
2   **Innovative Management Tools for Achieving Simultaneous Compliance**

1 This page intentionally left blank.
2

1   **Appendix E   Innovative Management Tools for Achieving Simultaneous**
2   **Compliance**
3
4
5   Systems simultaneously complying with the Long Term 2 Enhanced Surface Water
6   Treatment Rule (LT2ESWTR), Stage 2 Disinfectants and Disinfection Byproducts Rule (DBPR),
7   and other drinking water regulations may benefit from a broader, more holistic approach to water
8   system management. Therefore, EPA and other organizations are developing integrated, source-
9   to-tap management programs to assist water systems. These programs can provide a framework
10   within which water systems can identify simultaneous compliance concerns, prioritize them, and
11   adopt approaches to ensure that they will be in compliance with numerous regulations at the
12   same time.
13
14   This appendix identifies existing and developing programs that can help water systems
15   comply with regulations and produce consistently high quality water. These programs include
16   performance-driven and integrated management approaches that consider treatment processes
17   and operating practices throughout the entire water system. Systems are encouraged to consult
18   with primacy agencies and other systems with similar treatment facilities and water quality to aid
19   in carrying out these programs.
20
21   **Performance-Driven Optimization Programs**
22
23   Several programs have been developed for water systems to optimize treatment plant
24   performance. The Partnership for Safe Water (http://www.awwa.org/science/partnership/), for
25   example, has provided a successful approach for systems to improve turbidity removal in their
26   treatment plants and reduce microbial risks as addressed in the surface water treatment rules.
27   This section briefly describes an additional complementary approach to evaluating water
28   systems, identifying performance limitations, and establishing performance goals and standards
29   that guide water system operation.
30
31   *Microbial and DBP Comprehensive Performance Evaluations*
32
33   A comprehensive performance evaluation (CPE) is the evaluation phase of EPA's
34   Composite Correction Program. A Composite Correction Program is a systematic,
35   comprehensive procedure that identifies and corrects a unique combination of factors to improve
36   performance at filtration plants using existing facilities. CPEs are designed to identify and
37   correct limiting factors in the design, operation, maintenance, and administration of public water
38   systems that prevent compliance with drinking water regulations and optimized water system
39   operation. CPEs help systems prioritize ways to improve water system operation, and often
40   provide options without significant capital improvements as the highest priority option. CPEs
41   are designed to ensure that water systems consistently produce high quality drinking water.
42

1   While CPEs have primarily addressed pathogen control, efforts are underway to develop
2   a CPE methodology that addresses DBP control. A CPE for microbes or disinfection byproducts
3   (DBPs) consists of three components: performance assessment, major unit process evaluation,
4   and identification of factors that are limiting performance. The performance assessment
5   component determines a facility's status in achieving compliance for microbial and DBP
6   compliance requirements and performance goals and verifies the extent of any performance
7   problems at the plant. The major unit process evaluation determines if the various key existing
8   treatment processes in the plant, if properly operated, are of sufficient size to meet microbial and
9   DBP performance goals at the plant's current peak instantaneous operating flows. The last and
10   most significant component of a CPE is the identification of factors that limit the plant's
11   performance. CPEs are often conducted with the aid of primacy agency personnel or
12   consultants.

1

For more information on CPEs, please see:

Association of State Drinking Water Administrators. 2005. Total System Optimization – How Does it Relate to AWOP? Area-Wide Optimization Program News. 2(1). March 2005. Contact Alison Dugan at *dugan.alison@epa.gov* or Larry DeMers at *LDemersCO@aol.com*. *http://asdwa.citysoft.com/awop*

Center for Drinking Water Optimization Page (University of Colorado at Boulder) *http://bechtel.colorado.edu/cdwo/Welcome.html*

EPA's Drinking Water Academy Web site has numerous courses on conducting CPEs. *http://www.epa.gov/safewater/dwa/course-pwsoper.html*

U.S. EPA. 1998a. Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program. EPA 625/6-91/027. *http://www.epa.gov/ORD/NRMRL/pubs/625691027/625691027.htm*

Hegg, B.A. and L.D. DeMers. 2003. Performance Based Training: A Proven Approach to Improve Water Treatment Plant Performance. Presented at American Water Works Annual Conference. Anaheim, California. (June 15-19, 2003).

Jeschke, Rick, P.E. Plant Optimization at North Table Mountain Water and Sanitation District. Presented at the 2004 Joint Annual Conference of the Rocky Mountain Section of the American Water Works Association and the Rocky Mountain Water Environment Association. Grand Junction, Colorado. *http://www.rmwea.org*

Kentucky Division of Water. Area Wide Optimization Program. *http://www.water.ky.gov/dw/profi/awop/default.htm*

Swanson, Warren J., P.E. Assessing Plant DBP Performance Using the DBP-CPE. Presented at the 2004 Joint Annual Conference of the Rocky Mountain Section of the American Water Works Association and the Rocky Mountain Water Environment Association. Grand Junction, Colorado. *http://www.rmwea.org*

USEPA. 2004f. The Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) Implementation Guidance. (Appendix C) EPA 816-R-04-008.

USEPA. 2002c. Comprehensive Performance Evaluation (CPE): The Basics (Brochure). (EPA 816-F-01-020). November 2002.

U.S. EPA. 1999d. Guidance Manual for Compliance with the Interim Enhanced Surface Water Treatment Rule: Turbidity Provisions. EPA 815-R-99-010.

USEPA. 1998. CPE Training CD Optimizing Water Treatment Plant Performance Using the Composite Correction Program. EPA 625/6-91/027.

USEPA. 1998. Introduction to Comprehensive Performance Evaluations. EPA/625/C-01-011.

US EPA. Area Wide Optimization Program. http://www.epa.gov/reg3wapd/drinkingwater/optimization/

Integrated Management Approaches

It can be challenging for water systems to consider the impacts of specific management or operations decisions on their entire water system. Efforts have been made to develop or adopt management programs that consider the entire water system. Most of these programs are frameworks that managers can use to tailor a source-to-tap management program addressing issues and concerns specific to their water system. Because this approach is holistic (source-to-tap), such programs can serve as effective ways to consider simultaneous compliance issues. This section briefly describes a few source-to-tap integrated management approaches that, if used properly, could help a system achieve simultaneous compliance.

Hazard Analysis and Critical Control Point

The Hazard Analysis and Critical Control Point (HACCP) program has been used by the U.S. Food and Drug Administration for years, and has become an accepted management practice internationally to ensure the safety of food across the world. Recent research indicates that HACCP principles may be successfully applied to drinking water systems (Martel et al., 2006). HACCP is an integrated risk management approach that examines and assesses risks of drinking water contamination from the source to the tap. This information may then be used by drinking water systems to reduce the risk of contamination to the general public. An HACCP can be created and implemented by system management or with the help of expert consultants.

Seven basic principles are employed: hazard analysis; critical control point identification; establishing critical limits; monitoring procedures; corrective actions; verification procedures; and record-keeping and documentation. If a deviation occurs that indicates a loss of control, the water system detects the deviation and takes the appropriate, defined steps to reestablish control in a timely manner and ensure that potentially contaminated water does not reach the consumer and cause compliance problems with one or more regulation.

For additional information on HACCPs, please refer to the following resources:

AIChE. 2000. Guidelines for Chemical Process Quantitative Risk Analysis, Second Edition. Wiley.

Dewettinck T., E. Van Houtte, D. Geenens, K. Van Hege, and W. Verstraete. 2001. HACCP (Hazard Analysis and Critical Control Points) to Guarantee Safe Water Reuse and Drinking Water Production--a Case Study. Water Science & Technology. 43(12): 31-8.

Martel, Kathy, Gregory Kirmeyer, Amie Hanson, Melita Stevens, Joanne Mullenger, and Daniel Deere. 2006. Application of HACCP for Distribution System Protection. AWWARF Project #2856. Denver, CO.

Mullenger, J., G. Ryan, and J. Hearn. 2002. A Water Authority's Experience with HACCP. Water Supply. 2(5-6): 149-155. ©© IWA Publishing.

U.S. Food and Drug Administration. Hazard Analysis and Critical Control Point.
http://www.cfsan.fda.gov/~lrd/haccp.html

U.S. Food and Drug Administration. 1997. Hazard Analysis and Critical Control Point Principles and Application Guidelines. *http://www.cfsan.fda.gov/~comm/nacmcfp.html*

U.S. Food and Drug Administration Website. *http://www.cfsan.fda.gov/~lrd/haccp.html*

World Health Organization. 2004. Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking Water. Edited by M.W. LeChevallier and K.K. Au. ISBN: 1 84339 069 8. Published by IWA Publishing, London, UK.
http://www.who.int/water sanitation health/dwa/watreatment/en/

1
2
3
4   *ISO 14001*
5
6   The ISO 14001 provides management system standards that businesses, including
7   drinking water systems, may use to minimize adverse impacts on the environment, and to
8   continually improve environmental performance, enabling them to simultaneously comply with
9   multiple objectives.   ISO 14001 is typically implemented by a system's management staff,
10   possibly with the aid of consultants.

For more information on ISO 14001 please see:

American National Standards Institute (ANSI) Website. *http://web.ansi.org/*

Global Environment & Technology Foundation. Implementing Environmental Management Systems (EMS) in Public Entities. *http://www.getf.org/projects/muni.cfm*

Global Environment & Technology Foundation. 2002. Final Report: Second EMS Initiative for Government Entities (2000-2002).

Global Environment & Technology Foundation. 2000. The US EPA Environmental Management System Pilot Program for Local Government.

Grant, Gary, B.Sc., CEA, EMS(LA), CEAS. 2004. ISO 14001 and Drinking Water Quality. Environmental Science and Engineering. January, 2004. *http://www.esemag.com/0104/xcg.html*

International Organization for Standardization. *http://www.iso.org*

ISO 1400 Information Center. *http://www.iso14000.com/*

NSF International. 1996. NSF International Environmental Management System Demonstration Project - Final Report.

Pennsylvania's Multi State Working Group Pilot. 1999. The Effects of ISO 14001 Environmental Management Systems on the Environmental and Economic Performance of Organizations. March 27, 1999. *http://www.dep.state.pa.us/dep/deputate/pollprev/Tech_Assistance/mswgreport1.htm*

Redaud, J.L. 2005. ISO/TC 224 "Service Activities Relating to Drinking Water Supply Systems and Wastewater Systems - Quality Criteria of the Service and Performance Indicators". ISO. March 31, 2005. *http://www.pacinst.org/inni/WATER/ISOTC224Description.pdf*

Roig, R. and A. Saponara. 2003. ISO 14001 Environmental Management Systems: A Complete Implementation Guide. ISO. Available for purchase from: *http://www.stpub.com/pubs/allpubs.htm*

USEPA Web site. Voluntary Environmental Management Systems/ISO 14001. *http://www.epa.gov/owm/iso14001/*

USEPA Mid-Atlantic Region Web site. *http://www.epa.gov/region3/ems/emslinks.htm*

1
2
3
4

Additional Resources

AWWA. 1999d. Design and Construction of Small Water Systems, Second Edition. 228 pp.

Logsdon, G.S. et al. 2002. Filter Maintenance and Operations Guidance Manual. AWWARF Report 90908. Project #2511.

Renner, R.C. and B.A. Hegg. 1997. Self-Assessment Guide for Surface Water Treatment Plant Optimization. AWWARF Report 90736. Project #274.

Lauer, B. 2001. Self-Assessment for Treatment Plant Optimization, International Edition. AWWA Publication. 256 pp.

Smith, C.D., ed. 2005. Water Distribution System Assessment Workbook. AWWA. Denver, CO. 85 pp.

Westerhoff, G.P., et al. 1998a. The Changing Water Utility: Creative Approaches to Effectiveness and Efficiency. AWWA. Denver, CO.

1   This page intentionally left blank.